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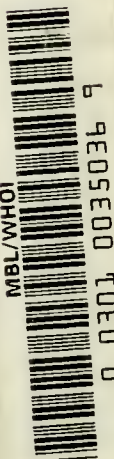
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EPIFAUNAL ZONATION and COMMUNITY STRUCTURE
in THREE MID- and NORTH ATLANTIC CANYONS

FINAL REPORT
for the
CANYON ASSESSMENT STUDY in the MID- and
NORTH ATLANTIC AREAS of the U. S. OUTER
CONTINENTAL SHELF

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ABSTRACT

The abundance and distribution of the epibenthic and coral fauna of three major canyons was studied using "Cheep Tow", a towed underwater camera sled. The three canyons surveyed were Baltimore, Lydonia and Oceanographer Canyons, with particular emphasis on the depths between 200 to 1000 meters. However, it was not always possible to obtain comparable coverage for all three canyons. Baltimore Canyon most closely resembled slope habitats. It has a high sedimentation rate and limited substrate variability in terms of extent of exposed outcrop, talus and glacial erratics. Lydonia and Oceanographer Canyons have much greater exposures of different substrate types, such as outcrops of rock and consolidated clay, talus, numerous glacial erratics and areas of extensive coral debris.

The shallow water fauna in canyons is similar to that found on the slope. It is composed of a variety of species that appear to have somewhat discrete depth ranges. In general, their distribution is patchy. The deeper water fauna is not as variable, except in areas that have exposed hard substrate. The fauna is usually dominated by three species, the crab *Geryon quinquedens* and two demersal fish *Synaphobranchus kaupi* and rattails. In areas of

exposed hard substrate shrimp, sponges and corals frequently dominate. The depth ranges of the deeper water fauna are usually quite broad. The higher concentrations of sessile filter-feeders in the northern canyons attest to the greater variety and extent of hard substrates found within them.

Community analysis did not identify any cohesive faunal assemblages. Rather the results indicate that the dominant taxa found in canyon habitats are independently distributed, with overlapping ranges in some areas and not in others. The most obvious factor controlling the occurrence of many of the species was availability of suitable substrate. The other factors controlling their distribution are not known. Most areas within the canyons were dominated by one species rather than a group of them. This again attests to the patchiness of the faunal distributions.

Corals, both alcyonarians and scleractinians were seen in all three canyons. The coral population of Baltimore Canyon tends to be less dense and diverse than it is in the other two canyons. The dominant coral in Baltimore Canyon is a small white sea pen that occurs on soft sediment between 100 to 300 meters depth. Both Lydonia and Oceanographer Canyons have high concentrations of a variety of corals. The three dominant species in these canyons, *Eunephthya florida* in Lydonia Canyon, and *Paramuricea grandis* and *Acanthogorgia armata* in Oceanographer Canyon, are all restricted to hard

substrate. Discrete assemblages of corals were not identified. The distribution of each species appears to be controlled by slightly different habitat requirements.

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INTRODUCTION

The canyon assessment study was divided into two parts. The first part consisted of a historical survey of the epibenthic fauna, with particular emphasis on corals, found off the coast of the northeastern United States. The data for this first part was mainly collected from photographs taken during previous dives of the submersible ALVIN. A detailed examination of the coral and epibenthic fauna of three major east coast submarine canyons was the objective of the second part of this study. The canyons chosen for this study were Baltimore, Oceanographer and Lydonia Canyons. By systematically classifying the faunal assemblages inhabiting these canyons it is hoped that possible "fragile" communities can be identified and avoided to lessen the impact of future resource development. The results of this survey can also be utilized as part of a baseline index for future environmental monitoring.

Until recently relatively little has been known about the fauna that inhabits major submarine canyon systems. Previous studies have been limited to small or not deeply incised canyon systems. One of these studies was further hampered by the fact that the method used to study the epifauna, benthic trawling, does not adequately sample localities of high relief such as are frequently found in canyons. Studies by Rowe and Menzies

(1969) and Rowe (1971) using combined camera lowerings and trawls resulted in the finding that the dominant species of continental slope assemblages were altogether absent or were present in reduced abundances in canyons. However, later work by Haedrich, Rowe and Polloni (1975) based on the results of 29 trawls, demonstrated that even though canyon fauna was not noticeably different from slope fauna several species could be recognized as being "canyon indicators".

The results of the historical survey show that canyon habitats differ significantly from slope habitats, and that the previous comparisons of slope and canyon epifauna do not adequately reflect the faunal constituency of large canyon systems (Appendix A). With regard to faunal assemblages canyons are particularly interesting in that they provide a heterogeneous environment, characterized by a variety of available substrate types, when compared to similar depths on the slope. The distribution of some species of epifauna is largely determined by the availability of suitable substrate (Hecker et al., 1978). As a result canyon assemblages differ from slope assemblages by being composed of a greater variety of trophic types. The most notable trophic type found in higher concentrations in canyons than on the continental slope are filter-feeders. They are usually sessile and many are restricted to the hard substrates, such as outcrops, boulders and talus blocks, that are common in deeply incised canyons.

Additionally, canyons have been identified as conduits for the channeling of material from the shelf to the rise and abyss (Rowe, 1972). This funneling characteristic also enables canyons to support a greater number of filter-feeders because of the resulting increase in nutrient flux.

Corals are an important constituent of canyon faunal assemblages. They are sessile filter-feeders and are frequently restricted to hard substrates. As a result of their feeding mode corals are dependent on particulate organic matter in the water column and thus favor environments with adequate current activity and nutrient load. As sessile organisms corals would be exceptionally susceptible to burial from increased sediment loading. This is further complicated by their morphological simplicity, the direct exposure of their tissue to the surrounding environment, increasing the probability of fouling. Thus, resource development that significantly alters water column characteristics in the vicinity of canyons would possibly be detrimental to these coral communities. As a result of their feeding type and lack of mobility corals make good "indicator organisms" for assessing potential environmental deterioration due to resource development.

There are distinct physical differences between the mid and north Atlantic canyons. Therefore, it might be expected that their faunal constituents would also differ. Baltimore

Canyon is a mid-Atlantic canyon and is thought to be largely inactive (Keller and Shepard, 1978). This would indicate that it is a site of high net deposition, being characterized by a high sedimentation rate and predominantly silty substrate with little exposed outcrop. In contrast, Oceanographer and Lydonia Canyons, located off Georges Bank, are sites of active erosion (Ryan et al., 1978). The low net deposition allows exposure of massive rock outcrops, as well as numerous talus blocks in their axes and glacial erratics on their walls. As a result of these physical differences it would be expected that corals and other filter-feeders would be a less important component of the fauna in Baltimore Canyon when compared to that of Oceanographer or Lydonia Canyons.

A study of canyon faunal assemblages is important in assessing the consequences of resource development for a variety of reasons. Their faunal communities are composed of a variety of trophic types with a particularly high proportion of filter-feeders. Of the various trophic types filter-feeders would probably be affected the most by activities that change the characteristics of the water column. Additionally, since canyons have been implicated in funneling nutrients from the shelf to the deeper regions of the continental margin, a thorough study of canyon habitats is important in assessing the possible farther ranging impact of resource development.

DATA SET

The coral and other epibenthic fauna of Baltimore, Oceanographer and Lydonia Canyons were studied using a towed underwater camera system. The field program took place during two cruises on the R/V EASTWARD in May, 1979. The photographs consisted mostly of 35 mm color slides and some 70 mm black and white prints. The photographic survey was also augmented by dredging for specimens to aid in species identification. The locations of usable camera footage are shown in Figures 1, 2 and 3. Areas in which continuous footage was obtained are denoted as a solid line; dashed lines indicate areas of discontinuous and therefore limited coverage. The efforts of the field program resulted in approximately 8000 usable photographs all of which were studied for this data set.

Unfortunately, limited comparable photographic coverage was obtained for all three canyons (Table I). In Baltimore Canyon data was obtained for parts of the axis, head and both walls in the depth interval from 100 to 1100 meters (Fig. 1). In Lydonia Canyon photographic coverage was obtained for parts of the axis, both walls and flanks between the depths of 100 to 1100 meters (Fig. 2). However, the coverage between 100 to 200 meters and 1000 to 1100 meters was quite sparse. No shallow water coverage was obtained in Oceanographer Canyon, thus the data is restricted to the depths between 400 and 1800

meters with limited coverage below 1600 meters (Fig. 3). The lack of adequate shallow water photographic coverage for the two northern canyons, Lydonia and Oceanographer, results from the presence of numerous lobster pot arrays along the walls and in the heads of these canyons. Thus, in order to avoid physical entanglement of the camera sled, as well as the resulting legal ramifications, it was necessary to restrict the photographic survey to the deeper parts of both canyons.

The photographic method for estimating abundance and distribution of epibenthos has various advantages over trawling or motion pictures. Both of these other methods tend to underestimate epifaunal density, while direct visual observation tends to overestimate it (Grassle et al., 1975). Barham, Ayer and Boyce (1967) compared measures of epifaunal density obtained by still photographs and 16 mm cinemaphotography along a transect in the San Diego Trough. The densities obtained from examination of the still photographs were nearly twice as high as those obtained from a study of the motion pictures. The investigators attributed this difference to the more critical examination possible with camera stills. A comparison of densities estimated from trawls versus still photographs shows that photographs yield densities an order of magnitude greater than those obtained from trawls (Haedrich, Rowe and Polloni, 1975). This is probably due to the fact that the more mobile components of the epifauna can readily

avoid the net. Additionally, the uncertainty of the actual configuration of the net with respect to the bottom is a problem that excludes trawling as a valid quantitative sampling technique.

The photographic sled "Cheep Tow" used in this survey consists of a welded aluminum channel frame with four glass buoyancy spheres mounted on top (Fig. 4). This configuration results in the sled being almost neutrally buoyant with the ability to right itself. A camera, strobe, Aandera current meter and pinger were mounted on the frame. Either a 35 mm EG & G or a 70 mm Hydroproducts camera was used for each tow. Both cameras were oriented facing front and tilted slightly downward. Exposures were taken at automatic 15 second intervals, with the time being marked adjacent to each frame.

The camera sled was towed at speeds between 0.8 to 1.2 knots, resulting in an average of 8 meters between successive frames (Appendix E). The triggering of a flash approximately 8 meters away may cause avoidance by some of the more mobile components of the epifauna. Uzmann et al. (1977) compared various sampling techniques and found that submersible and camera sled photographic techniques tended to underestimate the abundance of pelagic species. They suggest that a photo-negative response in pelagic forms may account for some of the differences observed, between photographic sampling and trawling, in estimating the abundance of these organisms.

However, other species may in fact be attracted to the light source, while many are probably not affected by it due to the limited visual apparatus expected in organisms inhabiting depths below the photic zone.

The sled was navigated by following tracings of the two pingers on a depth recorder. The pinger mounted to the sled allowed determination of when the sled was in contact with the bottom. The pinger on the cable showed obstacles and bottom irregularities before the sled encountered them, thus allowing manipulation of the sled to avoid them.

Unfortunately, not all obstacles could be detected, so the camera sled occasionally collided with the bottom. This frequently occurred in areas of outcrops or steep terraine. After a collision the camera sled frequently bounced off the bottom, and thus photographic footage of the area was not obtained. Additionally, areas of rough terraine were frequently avoided by raising the sled above bottom. As a result of these two factors the amount of hard substrate surveyed was substantially reduced. Since many coral species are restricted to hard substrate the data set is biased toward underestimating their occurrence and abundance. Another problem encountered during this survey was that the camera lens was occasionally covered with mud after collisions.

"Voucher" specimens and some sediment samples were obtained using a day dredge. In sampling epifauna dredging

has major disadvantages, namely avoidance by many of the mobile or burrowing organisms and poor recovery of fragile soft-bodied organisms. Another problem encountered while dredging was clogging with sediment. This latter problem was somewhat alleviated toward the end of the second cruise by removing the weight usually attached to the front of the dredge. This resulted in the dredge skimming the bottom rather than biting into it and thus allowing retrieval of more organisms. The "voucher" specimens aided in identification of some of the taxa observed on the photographs.

METHODS

Slide examination and species recognition

Estimates of the number of square meters viewed were made to calculate abundances of the faunal constituents. The method consisted of constructing and photographing a grid of 1 m² quadrants. The photograph of this grid was then projected onto a screen and traced. A correction factor of 2/3 was then applied to compensate for the refractive index of sea water. One major problem of the camera system on "Cheep Tow" is that the camera is oriented at a low angle with respect to the bottom. This results in each photograph covering a large area of the sea floor, but has the disadvantage of amplifying errors in estimates of the area viewed if the sled is tilted or off the bottom. Thus, any deviation from horizontal, or

change in elevation, substantially alters the size of the field viewed. In such instances estimates of the area were made in relation to the size of organisms or various topographic features. The viewable area for the 35 mm camera was approximately 11 m², while the area for the 70 mm camera was approximately 4 m².

Each slide was projected on the tracing of the area grid and examined. The time, area viewed, substrate, and species and their abundance was noted for each slide. This information was recorded in coded form on Opscan sheets (Appendix D). Depth for each photograph was obtained from the Aandera current meter, which, among other things, measured pressure depth in relation to time. Absolute species identification from photographs is exceedingly tentative. It is virtually impossible to identify each organism, seen on the photographs, to the species level. At present, the taxonomy of some major groups found below the photic zone is sketchy at best. This problem is compounded by the fact that the characteristics separating closely related species are frequently too fine to be discernable in a photograph. In many coelenterates the problem is further compounded by contraction of collected or disturbed organisms, such that their appearance in an undisturbed state is radically different. Within these constraints every effort was made to obtain as precise an identification as possible for each organism seen. The

"voucher" specimens and the background information collected during the historical survey greatly helped to achieve this end.

A major disadvantage of using underwater photographs to assess epibenthic faunal abundances is that biases may be created by the mere presence of the camera sled and its lights. For instance it has been noted that some fish are attracted to disturbances of the bottom, possibly to feed on the infauna exposed by displacement of sediment. Study of photographs would then tend to overestimate the abundance of these species. The abundances of other organisms, such as the large crab *Geryon quinquedens* and various fish are underestimated because they obviously try to avoid the path of the camera sled. Nothing could be done to alleviate these biases, because it is impossible to determine which organisms are there because of the presence of the sled or what organism has caused a dust cloud that may be seen in a photograph. Another bias which could not be compensated for is that the habitat of some organisms, such as burrowers or ones that hide beneath rocks, precludes an accurate assessment of their abundances because they are rarely out on the substrate and thus are not seen in the photographs. The most obvious of these is the lobster *Homarus americanus* which was seen only four times throughout this survey.

Statistical techniques

The species, their abundance and the m^2 viewed were summed for consecutive 100 meter depth intervals for each camera run. This data was also standardized by calculating the number of individuals per 100 m^2 , for each species and for the total fauna. The relative percent that each species contributed to the total fauna of that depth interval was also calculated. Additionally, the percent coverage of the different substrate types was calculated for each depth interval.

Two methods of community analysis were used, hierarchial classification and principal components ordination. The hierarchial classification was based on overall species similarity between samples (depth intervals). These samples were then consecutively combined into larger groups using the "unweighted" pair-group method (Sokal and Sneath, 1963). In this technique equal weight is assigned to each sample in a group, giving larger groups more weight than smaller ones. The species similarity index used was percent similarity (Whittaker and Fairbanks, 1958) given by the formula:

$$PS = 100 (1.0 - 0.5 \sum |p_{ia} - p_{ib}|) = 100 \min \sum (p_{ia}, p_{ib})$$

where p_{ia} is the proportion of sample "a" composed by species

"i" and p_{ib} is the same for sample "b". These values were

then used to assess faunal similarities between depths and various locations. This method basically measures and groups the samples by the degree of faunal overlap, in terms of species composition. The results are presented in cluster-diagram form, with the taxa responsible for the grouping identified.

The other method used to identify patterns of community similarity and species distribution was rotated principal components analysis. Each camera run was divided into consecutive 100 meter depth intervals. All species seen, and their abundances, within a depth interval were combined into a composite sample. After elimination of 100-meter depth intervals in which fewer than 50 m² were viewed, 153 composite samples were retained; 48 in Baltimore Canyon; 59 in Oceanographer Canyon and 46 in Lydonia Canyon. Of 155 recognizable taxa possibly occurring in the study area 65 were encountered. This resulted in a data matrix of 153 samples and 65 taxa. Ten categories or taxa were dropped from the quantitative analysis because they either provided no consistent faunal information, such as burrows, or because they occurred in such high concentrations that they were impossible to count and tended to obscure the distribution patterns of less abundant forms. In the latter case, the distribution of these taxa was considered separately.

Distributional patterns of faunal assemblages were studied

by analyzing the degree of species similarity between samples. This type of community analysis is usually referred to as Q-mode analysis (Poole, 1974). For this type of analysis the sample compositions are normalized to a standard unit length, so that the sum of squares of the species abundances within each sample is one. As a result each sample contributes equally to the analysis. It should be noted that this normalization of the data does not change the proportional contribution of the species to the sample composition.

The cosine-theta statistic was used as a measure of sample similarity. This measure can be visualized as the cosine of the angle between sample vectors, where the vectors are a geometrical representation of the samples' species composition in a hyperspace having dimensions equal to the number of species. The cosine-theta statistic is computed by post-multiplying the row-normalized data matrix by its transpose. This statistic ranges from zero when samples are very dissimilar (forming a large angle) to unity when the samples are identical (forming a small angle). The cosine-theta matrix was then analyzed for its eigenvalues (amounts of the sample accounted for by successive axes) and eigenvectors (composite-species axes defining faunal assemblages). This method allows for the fewest possible assemblages describing the maximum amount of the data, by constructing new component species axes so that each successive axis accounts for the greatest fraction of the remaining total sample variance.

These new principal component axes were rotated to a "best fit" position, defined by the Varimax criterion (Klovan and Imbrie, 1971). The principal components represent mathematically independent end-member samples (species or groups of species), with each real sample being described to a lesser or greater degree by an appropriate mixture of these end-members. Rotation of the components to a "best fit" position introduces no distortion or loss of information. The value of this technique is that the composition of the mathematically independent end-members tends to be close to real, and therefore more readily interpretable, samples. Each sample was then classified in terms of its faunal composition with respect to the identifiable end-member assemblages. The results of this analysis were then mapped in terms of the end-members best describing the fauna of each area viewed.

RESULTS AND DISCUSSION

Substrates

During the course of this study considerable variation in substrate type was noted, not only among the canyons, but also within them. By and large, fine grained sediments (silt and sand) predominate in all three canyons studied, with rock outcroppings generally restricted to the canyon axes and lower walls. Glacial erratics were also frequently found, particularly in the northern canyons.

In order to determine the spatial distribution of various

substrate types, sediment characteristics such as sediment type and sedimentary structure were systematically noted for each photograph examined. Detailed classification of substrate types using photographic evidence is limited because it is virtually impossible to determine grain size, composition, and the degree of consolidation of sediment in a photograph. However, it is possible to obtain from photographs some general information about the substrate types and their distribution. The photographic data was augmented by analysis of cored and dredged material in order to determine the nature of the sediments and particularly the outcrops within the canyons.

Silt and sand are the predominant sediment types in Baltimore Canyon, particularly in the shallower portion of the canyon and on the canyon walls. The thalweg has a sandy bottom with ripples along most of its length. In the mid part of the canyon at about 500 to 1000 m. there are outcrops of a fossiliferous grey siltstone, glauconitic black sandstone, and a fairly fine grained tan conglomerate. Some talus blocks from these outcrops were found on the canyon walls and in the thalweg. The fossiliferous siltstone and conglomerate were also recovered in a dredge on the west wall of the lower canyon. Dark grey well-consolidated clay of Pleistocene age outcrops was also found along the west wall of the canyon. A number of glacial erratics ranging in size from pebbles to boulders were also seen and dredged in this canyon. These

are particularly common in the axis. The prevalence of unconsolidated fine grained sediments with the limited exposure of rock supports the theory that Baltimore Canyon is an area of active sediment deposition.

The substrate distribution pattern in Lydonia Canyon is somewhat more complex than that seen in Baltimore Canyon. Silty sediment predominates on the flanks and walls of the canyon with occasional rock outcrops. Rock outcrops are more numerous in the axis of the canyon. Dredged material from these outcrops indicates that they are composed of a dark grey to black micaceous siltstone of mid to late Cretaceous age. Silty sediment in the thalweg of the canyon is rippled along most of its length. On the west wall and flank there are outcrops of consolidated clay as well as of rock. None of this material was recovered in dredges, so the lithology and geologic age of these outcrops is unknown. Above 400 meters on the east wall and flank of the canyon are large deposits of glacial erratics, mostly cobbles and pebbles with some shell hash. In general Lydonia Canyon appears to represent an area of active erosion of sediments, particularly within the canyon axis.

Oceanographer Canyon is the most deeply incised of the three canyons studied and also shows the greatest substrate variability. Silty sediment predominates on the lower

flanks of the canyon along with numerous glacial erratics ranging from cobbles to boulders. There are occasional rock outcrops on the east flank and a fairly extensive outcrop of consolidated clay in the 800 to 900 meter depth range on the west flank. Extensive outcrops of rock and consolidated clay form the steep walls on both sides of the canyon axis. Dredges on these walls yielded primarily dark grey to black micaceous siltstone of mid to late Cretaceous age along with some coarse, unfossiliferous conglomerate. The micaceous siltstone is the same as that found in Lydonia Canyon. Numerous cobbles and boulders were also found on the axis walls. These may be talus blocks from the canyon walls or glacial erratics. Silty and sandy sediments in the thalweg are generally rippled. The extensive rock outcrops and concentrations of glacial erratics in this canyon indicate that it is probably undergoing active erosion. For a more detailed discussion of the geology the reader is referred to Appendix F.

Fauna not considered in statistical analyses

Several types of organisms encountered during this survey are excluded from the faunal analyses. The rationale is that where these organisms are found their abundances are usually much too high to allow accurate quantification. These exceedingly high densities also have the tendency to obliterate any other faunal trends. Additionally, species characterization

of these taxa is frequently not possible. Many delicate pink stalked organisms are found between 100 to 200 meters on the walls of Baltimore Canyon. They appear to be restricted to areas of fine grained sediment and thus are not found in the axis. A possible taxonomic identification could be that they are a type of stalked hydroid. These stalked organisms are gelatinous, so their translucent nature precludes structural determination from photographs. However, occasional shadows indicate that they do have some sort of tentacle crown. Identification was further complicated by the fact that their composition appears to be too fragile to allow retrieval of "voucher" specimens by dredging, since none were recovered during the field program. These stalked organisms were not observed in Lydonia or Oceanographer Canyons. However, no conclusions can be made as to their geographic distribution, because adequate shallow water coverage was not obtained in the northern canyons.

Another type of organism for which quantification is virtually impossible is a species of the sponge genus *Cladorhiza*. This sponge occurs in high concentration in all three canyons, and is most common in areas of semiconsolidated clay. In Baltimore Canyon *Cladorhiza* sp. occurs between 600 to 800 meters in the axis and slightly shallower on the walls. The sponge occurs between 200 to 700 meters on both flanks of Lydonia Canyon, with exceptionally heavy concentrations

of it being restricted to occasional patches on the east flank. In Oceanographer Canyon very high abundances of *Cladorhiza* sp. occur between 500 to 1000 meters on both flanks of the canyon. They are also found in somewhat lower concentrations in the same depth range within the axis of this canyon.

Unidentified polychaete tubes were also encountered in this study though no animal was ever seen protruding from them. They differ from the tubes of the quill worm *Hyalinoecia artifex* in that they are curved, smaller, and most frequently are seen sticking out of the substrate rather than lying on top of it. They are found in areas having soft silty sediment. The sponge *Cladorhiza* sp. and these polychaete tubes appear to be mutually exclusive, meaning that in areas where one is exceedingly common the other one is not found. This is probably a reflection of their different substrate preferences. In Baltimore Canyon high concentrations of these tubes occur at depth exceeding 800 meters both in the axis and on the walls. High concentrations of polychaete tubes are found only between 800 to 1000 meters in the axis of Lydonia Canyon, while decreased abundances occur shallower in the axis and on the west wall. Occasionally, patches of heavy concentrations of these tubes are also found on both flanks of the canyon between the depths of 500 to 1000 meters. The substrate variability in Lydonia Canyon allows both *Cladorhiza* sp. and the polychaete tubes to occupy the same

depth interval, but again they are rarely found in the same area. The polychaete tubes were never found in high concentrations in Oceanographer Canyon.

The other type of organism for which quantification was not obtained is a small colonial hydroid. Previous observations made from a submersible indicate that these hydroid colonies inhabit substrates consisting of a thin veneer of silt overlying a hard crust. Many of these hydroids were obtained during the dredging in Baltimore Canyon, but no large concentrations were seen during the photographic survey of that canyon. In Lydonia Canyon these colonial hydroids are found in several patches on the walls of the canyon. The highest concentrations of hydroid colonies are found along the west wall of the axis of Oceanographer Canyon between the depths of 500 to 800 meters, with occasional sparse patches in other areas.

Faunal density

The density of epibenthic fauna varies with depth. Figure 5 shows the faunal density with respect to depth for the three canyons combined. Densities are high in the shallow depths with a peak between 300 to 400 meters. A second peak occurs between 1700 - 1800 meters. Between 600 to 1500 meters densities are uniformly low. The high faunal density between 300 to 400 meters was mostly the result of high concentrations of the quill worm *Hyalinoecia artifex* and small encrusting

anemones found on glacial erratics in the northern canyons. These species have a very patchy distribution and occur in high concentrations when they are present. The distribution of the anemones is controlled by substrate availability, because they are always attached to larger cobbles and boulders. The second peak, between 1700 to 1800 meters, reflects the high concentrations of the deep sea brittle star *Ophiomusium lymani* found at these depths.

Figures 6, 7 and 8 show the faunal density with respect to depth for each of the three canyons, Baltimore, Lydonia and Oceanographer respectively. In general, densities are higher in the shallow water of both Baltimore and Lydonia Canyons. Unfortunately, no comparable coverage was obtained for Oceanographer Canyon. The peak in density in Baltimore Canyon between 300 to 400 meters is due to the presence of *Hyalinoecia artifex* (Fig. 6). In Lydonia Canyon densities are uniformly high between 100 to 400 meters (Fig. 7). The galatheid crab *Munida valida* is found in high concentrations between 100 to 200 meters. However, as coverage in this region was limited to only 160 m² viewed, caution should be used in assessing the universality of their abundance in this region. Between 200 to 300 meters the high faunal density is due to the presence of small anemones, while between 300 to 400 meters both the anemones and *Hyalinoecia artifex* are present in high concentrations. Below 400 meters the faunal density in all three

canyons is similarly low.

Comparisons of the field data with the results of faunal density during the historical survey indicate that both follow the same general trend (Fig. B-2, Appendix A), with one notable exception. The densities in the middle depth region (600-1600 meters) were somewhat higher in the historical survey. This discrepancy in absolute values may be due to the low angle of the "Cheep Tow" camera with respect to the bottom magnifying errors in the estimates of area viewed. Another factor explaining this difference could be that less coverage of hard substrates was obtained during the field program and such areas tend to support more abundant fauna.

Faunal components

Previous work has shown that the relative abundance of faunal components changes with depth (Haedrick, Rowe and Polloni, 1975; Grassle et al., 1975; Appendix A). Generally, the faunal assemblages of shallow-water regions are composed of a variety of taxonomic groups and trophic types. The high concentration of particulate nutrients on the shelf and upper slope support a variety of organisms. The faunal assemblage of mid-slope depths is dominated by demersal fish, such as eels and rattails, and the red crab *Geryon quinquedens*. These organisms are large mobile predators and scavengers, with the ability to cover large areas in their search for food. This reflects the lower nutrient flux in the middle depth

range. The lower slope and continental rise assemblage is dominated by one trophic type, deposit feeding echinoderms, reflecting the lower nutrient availability in this region.

The results of the historical survey indicated that the general trend, of gradual replacement of trophic types with increasing depth, is somewhat obscured in submarine canyon habitats. The greater environmental heterogeneity, with regard to substrate variability, afforded by canyons coupled with nutrient enrichment was identified as a probable cause for this phenomenon. Both these factors would allow canyons to support a greater variety of trophic types than found at comparable depths on the slope. The more intensive study of individual canyons undertaken during the field program supports these earlier findings.

The major taxonomic groups seen during the field survey were fish, crustaceans, anemones, polychaetes, sponges, echinoderms and corals. Of the three canyons studied Baltimore Canyon most closely resembles a slope habitat. This is reflected by a mapping of the major faunal components found in this canyon (Fig. 9). The similarity to slope conditions is probably due to the fact that Baltimore Canyon exhibits less substrate variability than either of the two northern canyons. Except for relatively few rock outcrops and occasional occurrences of cobbles and boulders the walls of this canyon are

primarily silty. The axis of the canyon has predominantly sandy sediment with sparse talus deposits. One particularly interesting area encountered was on the west wall, between 100 to 300 meters, which had a deposit of numerous large boulders.

The shelf assemblage in Baltimore Canyon is dominated by one trophic type, two species of crustaceans: the galatheid crab *Munida valida* and the jonah crab *Cancer borealis*. Slightly deeper on the canyon walls and in its head the fauna is dominated by several trophic types represented by three species: the crustacean *Cancer borealis* which is a carnivore and scavenger, a fluffy white sea pen which is a filter-feeder, and the burrowing anemone *Cerianthus borealis* which is a carnivore. The fauna of the axis and canyon walls, between 300 to 500 meters, is dominated by the scavenging quill worm *Hyalinoecia artifex*. This organism has a patchy distribution and is present in very high concentration in regions where it occurs. Slightly deeper in the axis and on some parts of the mid-west wall two species of anemone predominate, *Bolocera tuediae* and a species of cerianthid. *Bolocera tuediae* is restricted to hard substrates and was found on the occasional talus blocks and cobbles in this area. The talus occurs slightly downslope of where the canyon constricts and turns. Below 600 meters in the axis and on the wall the fauna is dominated by carnivores and scavengers: two types of demersal

fish, rattails and the deep-sea eel *Synaphobranchus kaupi*, and the red crab *Geryon quinquedens*. Thus, Baltimore Canyon exhibits faunal trends similar to those found on the slope, particularly with regard to the increasing dominance of fish and crustaceans in the middle depth range.

A slightly more complex pattern is evidenced in Lydonia and Oceanographer Canyons. This is probably a reflection of the higher degree of substrate variability found at intermediate depths within these canyons. Lydonia Canyon is characterized by exposure of large rock and consolidated clay outcrops in the axis. The west wall and flank of this canyon is characterized by silty sediment with steep consolidated clay slopes. The east flank is characterized by silty sediment with numerous glacial erratics ranging in size from pebbles to boulders.

The faunal components of Lydonia Canyon are shown in Fig. 10. The shallow water fauna (200 to 400 meters) is dominated by the crustacean *Munida valida*, the starfish *Asterias vulgaris*, and several species of anemone *Cerianthus borealis*, *Actinauge longicornis*, *Bolocera tuediae*, a small unidentified anemone and many small anemones that may be juvenile forms. With the exception of *Cerianthus borealis* these anemones are found on the numerous glacial erratics present in this depth range. Slightly deeper (400 to 700 meters) the east flank fauna is dominated by *Hyalinoecia artifex*, which is replaced by fish at greater depths. The fauna of the

west flank is mainly composed of two species of crustaceans, a small bottom dwelling shrimp and the red crab *Geryon quinquedens*, and fish, with occasional patches of *Hyalinoecia artifex* in the shallow region. Farther up the canyon sponges dominate the fauna. In the axis major components of the fauna are shrimp and a variety of corals. Most of these corals are species that are restricted to hard substrates. The gorgonian *Paramuricea grandis* and the solitary scleractinian *Desmophyllum cristagalli* are found in the deeper axis, while the alcyonacean *Eunephthya florida* is common farther up the axis. Toward the head of the canyon the coral *Pennatula aculeata* is quite common between 400 to 600 meters. This species is restricted to soft substrates.

The substrate types in the axis of Oceanographer Canyon were exceedingly diverse, with massive outcrops of rock and consolidated clay on the walls of the axis and numerous talus blocks on the canyon floor. The west flank of this canyon is characterized by predominantly silty sediment, with a field of glacial erratics and occasional outcrops of consolidated clay. The east flank of Oceanographer Canyon is similar except that it has more extensive glacial erratic fields.

The faunal components found in various areas of Oceanographer Canyon are shown in Fig. 11. The fauna of the west flank is composed of a variety of trophic types: two crustaceans, a shrimp and the crab *Geryon quinquedens*; two types of demersal

fish, rattails and the eel *Synaphobranchus kaupi*; and numerous sponges which are attached to the glacial erratics. These glacial erratics also provide hard substrate for the attachment of several species of coral, the most common one being the gorgonian *Acanthogorgia armata*. The fauna of the east flank is dominated by two taxa, sponges and shrimp. A number of corals, two species restricted to hard substrates, are also found in this region namely *Acanthogorgia armata* and *Paramuricea grandis*. The faunal components found on both the west and east walls along the axis are shrimp and the same two corals *A. armata* and *P. grandis*. The fauna in the deeper part of the axis is mainly composed of two trophic types, the deposit feeding brittle star *Ophiomusium lymani* and the filter feeding sea pen *Pennatula aculeata*. Between 1100 to 1600 meters in the axis of Oceanographer Canyon the fauna is heavily dominated by rattails and the eel *Synaphobranchus kaupi*. The consistently higher proportion of sessile filter-feeders, namely corals and sponges, found in Oceanographer Canyon directly reflects the greater exposure of hard substrates in this canyon.

In some areas of Oceanographer Canyon the camera tracks were very close to ALVIN dive tracks. This allows comparisons to be made between the two methods of surveying epibenthic fauna. Data from these dives were presented for 50-meter depth intervals in the historical survey. For comparative

purposes this data is presented on Fig. 11 for 100-meter depth intervals and is marked by a star adjacent to the circles. In the flat narrow axis both methods gave similar results, namely a high concentration of echinoderms below 1600 meters. On the west wall the two methods gave somewhat different results. The submersible coverage reflected consistently higher concentrations of corals. A more detailed comparison of the two methods is discussed in a later section of this report.

In general these results are consistent with the trends of faunal components of canyon assemblages identified in the historical survey, namely a variety of trophic types composing the fauna found throughout the depth range studied, with significantly more sessile filter-feeders in the middle depth range. This is in contrast to the sole predominance of fish and the crab *Geryon quinquedens* at these depths on the slope. The higher exposure of hard substrate and greater flux of particulate nutrients in canyons are probably the primary factors accounting for this difference between canyon and slope fauna.

Community analysis

To delineate faunal assemblages within the canyons studied two methods of community analysis were used, clustering based on species similarity and principal components analysis.

The species similarity measure relies on the degree of faunal overlap, in terms of species shared, between the samples. The clustering of the samples is based on their entire faunal complement, and thus tends to group samples of similar taxonomic composition. Conversely, principal components analysis attempts to group species which have similar distributions, such that the maximum amount of variance in the data set is accounted for by the fewest species or faunal assemblages. The taxonomic composition of each sample is then explained in terms of these species. Both of these methodologies gave similar results.

Community analysis showed some marked differences in faunal assemblages between the three canyons studied. While a few basic patterns common to these canyons may be identified local variations within the individual canyons, such as substrate differences, tend to enhance faunal variability. Baltimore Canyon exhibits the least amount of substrate variability of any of the three canyons, thus the fauna of this canyon tends to resemble that found on the continental slope.

Species similarity measures between the areas surveyed in Baltimore Canyon identify a diverse shallow-water assemblage with a somewhat more homogeneous deeper one (Fig. 12). The dominant species in the shallower parts of Baltimore Canyon are the galatheid crab *Munida valida*, the starfish *Asterias vulgaris*, an unidentified fluffy white sea pen, the jonah crab *Cancer*

borealis, the large burrowing anemone *Cerianthus borealis* (Fig. 13b) and the quill worm *Hyalinoecia artifex* (Fig. 13d). *M. valida* and *A. vulgaris* dominate the shelf fauna (100 to 200 meters). The white sea pen is found in localized areas between the depths of 200 to 300 meters, while *Cancer borealis* with occasional occurrences of *Cerianthus borealis*, dominates the slightly deeper fauna. *Hyalinoecia artifex* is the most common species found between 300 to 500 meters on the walls in the lower part of the canyon and in various areas in the axis. Within the shallow-water depth range only one area was encountered, in the photographic survey, that has a totally different faunal composition. This area is located between 100 and 300 meters depth on the west wall in the middle of the canyon, and is characterized by a large boulder deposit. The surfaces of these boulders are covered by numerous large white anemones (Fig. 13a). In addition, several species of crabs and fish are also found in this area. This region is very unique, in terms of faunal composition and absolute abundance, when contrasted to other areas of the canyon within this depth range. Similar boulders and anemones were also retrieved in a dredge taken on the east wall of the canyon. Norfolk Canyon also has several areas with similarly high concentrations of this white anemone attached to cobbles (encountered on ALVIN Dive 574 and Robert Embley, pers. comm.). At this time there is insufficient ancillary data available to determine what

factors govern the occurrence of these anemone beds. The deeper water fauna of Baltimore Canyon is rather homogeneous, with rattails and the red crab *Geryon quinquedens* dominating the faunal assemblage.

Principal components analysis of the fauna observed in Baltimore Canyon resulted in 89% of variance in the data set being explained by ten end-members or twelve species. Eight of these end-members are monospecific, meaning that the distributions of these species are independent of each other and of all other species in the data set. The other two end-members are dispecific, being composed of two species that are positively correlated in terms of their distribution. The high proportion of monospecific end-members indicates that no cohesive grouping (i. e. a community) of interdependent species occurs throughout the canyon, meaning that dominant members of the fauna are controlled by different factors. On closer examination of the results of this analysis the general pattern of gradual species replacement with increasing depth emerges.

The species composing the first ten end-members, as well as a plot of their occurrence in Baltimore Canyon, are shown in Fig. 14. Examination of the occurrences of these end-members identifies the faunal trends. The shallow-water fauna is composed of six of these end-member groups (2, 3, 4, 7, 8 and 10). The galatheid crab *Munida valida* and the starfish *Asterias vulgaris* (10), dominant between 100 to 200 meters,

are replaced by either *Cancer borealis* (2), *Cerianthus borealis* (4), the white sea pen (7), or combinations of two of these end-members, in slightly deeper water (200 to 300 meters). *Hyalinoecia artifex* (3), as well as *Cancer borealis* and *Cerianthus borealis* compose the faunal assemblage of the next depth interval (300-500 meters). In the shallower part of the axis two end-members dominate the fauna. These are the quill worm *H. artifex* (3) and two anemones *Bolocera tuediae* (Fig. 13d) and a species of *Cerianthidae* (6). In both the axis and on the walls of Baltimore Canyon three monospecific end-members (1, 5 and 9) compose the faunal assemblage found below 500 meters. These are two types of demersal fish, rattails (1), and the deep-sea eel *Synaphobranchus kaupi* (9), (Fig. 15b), and the red crab *Geryon quinquedens* (5) (Fig. 15a). The gradual replacement of species across bathymetric contours is characteristic of faunal trends found in slope habitats of the continental margin (Appendix A).

Species similarity measures between different areas in Lydonia Canyon yield some similarities with Baltimore Canyon, but identify one major difference. Again, the shallow-water assemblage is diverse and is accompanied by a somewhat less variable deeper assemblage (Fig. 16). The main difference is that the substrate in the deeper parts of this canyon is quite variable. The areas characterized by mixed substrate types tended to cluster together, because of the presence of numerous

small shrimp that congregate around outcrops and boulders (Fig. 15d). The shallow water fauna is again dominated by the galatheid crab *Munida valida* and the burrowing anemone *Cerianthus borealis*. However, several other anemones, *Bolocera tuediae*, a small unidentified encrusting anemone and what appear to be juvenile anemones are also found in high concentrations in the shallower depth. Notably the jonah crab *Cancer borealis*, the starfish *Asterias vulgaris* and the white sea pen do not dominate the shallow-water fauna in Lydonia Canyon. However, the shallow water coverage of this canyon is rather limited, so the fact that these organisms did not dominate the areas surveyed may just be a reflection of their patchy distribution, or the high abundances of the small unidentified anemone. The quill worm *Hyalinoecia artifex* is again a dominant part of the fauna, but is found in deeper water. The red crab *Geryon quinquedens* and the eel *Synaphobranchus kaupii* are also important species in the deeper parts of the canyon, while shrimp dominate the fauna in areas that have exposed hard substrates.

The principal components analysis of the fauna of Lydonia Canyon results in 89% of the variance being explained by ten end-members, or fourteen species. Seven of these end members are monospecific, two are dispecific and one is composed of three species. Again, this points to the fact that the majority of the dominant species are independently distributed and thus

do not form cohesive groupings. Interestingly, the distributions of *Cerianthus borealis* and *Bolocera tuediae* are not correlated in Baltimore Canyon, while they are correlated in Lydonia Canyon. It is quite possible that the appropriate environmental factors required by *B. tuediae* are not found in Baltimore Canyon in the depth range inhabited by *C. borealis*. Another possibility is that *B. tuediae* which requires hard substrate for attachment, is excluded from shallow water in Baltimore Canyon by the presence of the large white anemone. This difference, however, does indicate that *B. tuediae* is not restricted to a discrete depth range.

The ten end-members of the fauna of Lydonia Canyon are identified and plotted in Figure 17. Again, the pattern for the shallow-water assemblage is one of gradual replacement of species across bathymetric contours. *Munida valida* (6) dominates the fauna above 200 meters, while three anemones, *Cerianthus borealis* and *Bolocera tuediae* (7) and a small encrusting anemone (5) gain importance in the slightly deeper fauna. On the east flank and wall of Lydonia Canyon this pattern is quite obvious with the anemone (5), which is attached to the glacial erratics found in this area, gradually being replaced by *Hyalinoecia artifex* (2) at increasing depths. The fauna of the west flank and wall of the canyon is consistently dominated by *Geryon quinquedens* (4) above 500 meters, which is replaced by *Synaphobranchus kaupi* (3) and shrimp (1) at greater depths.

The fauna in the axis of Lydonia Canyon is also heavily dominated by shrimp (1). This reflects the greater amount of hard substrate exposed within the axis and along the lower parts of the walls. Two areas were identified in Lydonia Canyon that deviated from these general trends. An area of consolidated clay is located between 400 to 500 meters on the west flank. The fauna here is dominated by a species of *Munida*, which may be *Munida valida* since specimens have been trawled from depths exceeding 500 meters (Haedrich and Rowe, unpublished results). Additionally, in the shallow axis high concentrations of *Pennatula aculata* are found between 400 and 600 meters.

Species similarity analysis of the fauna of Oceanographer Canyon does not show as distinct a pattern as was found in the other two canyons (Fig. 18). This difference is probably the result of the lack of shallow water coverage, so that the variable shallow-water assemblage was not seen. However, the results do show a more complicated pattern for the deeper fauna. The faunal variability within this depth range is probably caused by the heterogeneous substrates found within this canyon. In areas of silty sediment the fauna is dominated by the red crab *Geryon quinquedens*, the eel *Synaphobranchus kaupi* and rattails, with the ophiurid *Ophiomusium lymani* dominating the fauna in the deeper axis. In areas characterized by variable substrate, including numerous

outcrops, the fauna is composed mainly of shrimp and sponges with several locations having high concentrations of the coral

Principal components analysis of the fauna of Oceanographer Canyon resulted in 96% of the total variance being explained by ten monospecific end-members. The plot of the end-members of the fauna of Oceanographer Canyon shows that trends of faunal replacement are not as apparent in this canyon, as they were in Baltimore or Lydonia Canyons (Fig. 19). This finding again indicates that a possible reason for the lack of pattern in Oceanographer Canyon is the heterogeneous environment, in terms of substrate variability, afforded by this canyon.

The fauna in the axis is heavily dominated by shrimp (1) in the depth interval between 500 and 1000 meters. This part of the canyon has numerous exposures of hard substrate, providing suitable habitats for these organisms. Along the east wall of the axis the gorgonian *Paramuricea grandis* (4) occasionally dominates the fauna or co-occurs with the shrimp. Slightly deeper in the axis, the fauna is dominated by two kinds of demersal fish, the eel *Synaphobranchus kaupii* (6) and rattails (3), and a species of cerianthid anemone (7). Below 1700 meters the ubiquitous brittle star *Ophiomusium lymani* (8) dominates. The fauna of the east flank of Oceanographer Canyon is almost totally dominated by the sponges

that are attached to the numerous glacial erratics commonly found in this area. Other important fauna in this region were shrimp (1) and the alcyonacean *Eunephthya florida* (10). The fauna of the west flank is dominated by *Geryon quinquedens* (5) in the shallow region, with sponges (2), shrimp (1) and the deep-sea eel *Synaphobranchus kaupi* (6) occurring slightly deeper. The fact that various localities are frequently occupied by more than one end-member also attests to the environmental heterogeneity found within this canyon. These findings are in agreement with the results of the historical survey which identified Oceanographer Canyon as having a highly variable faunal assemblage.

To compare the fauna of the three canyons a rotated principal components analysis was run for the entire data set. This resulted in a data matrix of 153 samples and 59 species. Eighty-five percent of the sample variance was explained by the first ten end-members, or eleven species (Table II). Nine of these end-members are monospecific, meaning that dominant species are independently distributed. This result again substantiates the findings of the historical survey. Of a total of 153 samples, 141 of them were explained by one or more of these end-members.

In Table III the end-members are listed against depth in the three canyons. The faunal differences between Baltimore Canyon and the northern canyons are quite apparent. The

shallow-water fauna in Baltimore Canyon is dominated by five end-members; the jonah crab *Cancer borealis* (10), the burrowing anemone *Cerianthus borealis* and some unidentified anemones (8), the quill worm *Hyalinoecia artifex* (3), the galatheid crab *Munida valida* (7) and sponges (4). The fauna below 400 meters was generally dominated by rattails (2), with occasional occurrences of the red crab *Geryon quinquedens* (5), the deep-sea eel *Synaphobranchus kaupi* (6) and a small burrowing cerianthid anemone (9).

In contrast the fauna of the northern canyons was frequently dominated by different taxa. Comparable shallow water coverage was not obtained in Oceanographer Canyon and is very sparse in Lydonia Canyon. However, some of the same species that dominate the shallow fauna in Baltimore Canyon also dominate the fauna in Lydonia Canyon. These are *Cerianthus borealis* and some small unidentified anemones (8), *Munida valida* (7) and *Hyalinoecia artifex* (3). In both of the northern canyons the fauna below 400 meters is now frequently dominated by shrimp (1). The fauna in Oceanographer Canyon between the depths of 400 and 1099 meters is also occasionally dominated by several of the taxa found in Baltimore Canyon; sponges (4), *Synaphobranchus kaupi* (6), rattails (2) and *Geryon quinquedens* (5). At comparable depths in Lydonia Canyon the only major difference is that sponges (4) less frequently dominate the fauna. Coverage below 1100 meters was limited

to Oceanographer Canyon, where shrimp (1), rattails (2), *Synaphobranchus kaupii* (6) and sponges (4) again predominated, with occasional occurrences of a burrowing cerianthid anemone (9).

The main differences in the fauna between Baltimore Canyon and the two northern canyons are in taxa that prefer or require hard substrates. Both Oceanographer and Lydonia Canyons support sizable populations of these organisms, in addition to the fauna usually found in soft substrate areas. One other noticable difference among the faunal components of the three canyons is that the quill worm *Hyalinoecia artifex* does not dominate any of the areas in Oceanographer Canyon. This is the result of no shallow-water coverage in that canyon and also reflects the patchy distribution of this species. However, many individuals of *H. artifex* were found in the axis of this canyon during the historical survey (Appendix A).

Depth zonation

The dominant epifauna observed in the three canyons can generally be divided into the major depth zone groupings delineated by Haedrich, Rowe and Polloni's (1975) study of epifaunal zonation on the slope south of New England. The common taxa or species were ranked by their relative abundance, rather than numerically, in the depth zone in which they comprised the greatest proportion of the fauna. This method alleviates

some of the biases created by unequal coverage of the respective depth zones. However, this method does not alleviate the bias caused by patchy distribution. Thus, care should be taken in assessing the universality of the dominance of various taxa within a particular depth zone.

Table IV lists the common epifauna observed in Baltimore Canyon by depth zone. A large white anemone, found on boulder deposits in one area of the west wall (150-300 m), dominates the shallow-water assemblage. Even though comparable depth coverage was obtained, throughout this canyon, the anemone was not seen in any of the other areas. This illustrates the problems caused by the patchy distribution of many of the faunal constituents, since the white anemone accounts for 31% of the total shallow zone fauna but was restricted to only one area. Several of the other common fauna observed in this depth zone are similar to those found by Haedrich, Rowe and Polloni (1975), namely *Munida valida* and *Cancer borealis*. Conspicuously missing from their shallow depth samples are the large burrowing anemone *Cerianthus borealis* and the unidentified fluffy white sea pen. Possible reasons for this discrepancy could be that a trawl does not adequately sample burrowing organisms and the white sea pen has a rather patchy distribution. Of the fauna dominating the middle depth zone five of the most common taxa observed in Baltimore Canyon are the same as those found by Haedrich, Rowe and Polloni (1975). These are the

quill worm *Hyalinoecia artifex*, the deep-sea eel *Synaphobranchus kaupi*, the red crab *Geryon quinquedens*, rattails and hakes. This agreement attests to the similarity between habitats found in Baltimore Canyon and on the slope.

A slightly different pattern is found in the zonation of epifauna in the two northern canyons. Table V lists the common taxa observed in Lydonia Canyon. Anemones again dominate the fauna of the shallow depth zone. These are a small encrusting anemone that is attached to many of the glacial erratics found in this canyon, the burrowing anemone *Cerianthus borealis*, *Actinauge longicornis* and numerous small anemones that appear to be juveniles. Several of the dominant taxa found in the middle depth zone of Lydonia Canyon differ substantially from those commonly found on the slope. These are organisms that are usually associated with hard substrates. The small encrusting anemone, the anemone *Bolocera tuediae*, and sponges are attached forms restricted to hard substrates, while the shrimp prefers areas of high relief such as outcrops and boulders. However, some of the other fauna in the middle depth zone is similar to that commonly found on the slope and in Baltimore Canyon. The differences in faunal constituents attest to the greater availability of hard substrate in Lydonia Canyon.

Coverage in Oceanographer Canyon was limited to the middle and deep zones. Table VI is a listing of the common

taxa observed in this canyon. Examination of this table, again, points to the availability of hard substrate determining the occurrence of various taxa. The middle depth zone is dominated by organisms that require or prefer hard substrates. These are shrimp and sponges. In the lower depth zone the ophiurid *Ophiomusium lymani* is the most abundant species, however, all of these individuals were seen in one area, between 1700 and 1800 meters in the axis of the canyon. *O. lymani* is also the dominant component of slope fauna at comparable depths. Attached forms common in Oceanographer Canyon in this depth zone are the gorgonians *Paramuricea grandis* and *Acanthogorgia armata* and sponges.

The differences between the fauna observed in this study when compared to that commonly found on the slope are in the greater proportions of taxa requiring or preferring hard substrates. Table VII is a listing of these organisms ranked by their relative contribution to the total hard substrate fauna in their respective depth zone. The large white anemone accounts for the majority of the attached fauna in the shallow zone of Baltimore Canyon. Shrimp and several anemones are the dominant hard substrate forms in the middle depth zone of this canyon. The hard substrates in the shallow and middle depths of Lydonia Canyon are also dominated by anemones, with shrimp becoming increasingly important at greater depths. Also many corals are found on the exposed hard substrates in this

canyon. In Oceanographer Canyon shrimp are one of the most important components of the hard substrate spifauna. The middle depth zone is dominated by shrimp and sponges, while the most common taxa in the deeper zone is the gorgonian *Paramuricea grandis*. Again, various species of corals are also found on the hard substrates of this canyon.

The results of the historical survey identified a trend of faunal emergence at higher latitudes (Appendix A). This means that the depth range of various species, particularly with regard to peak densities, is shallower in the north than it is in the south. Emergence with increasing latitude was most pronounced in shallow water organisms. Some examples of this trend are also seen in the results of the field survey. However, this comparison is substantially hampered by the scarcity of shallow water coverage in Lydonia Canyon and the lack of comparable coverage in Oceanographer Canyon. Figure 20 shows the depth distribution of four of the major species composing the shallow water faunal assemblages. The white sea pen was only found in Baltimore Canyon where it occurs between 100 to 300 meters, with highest abundances between 200 to 300 meters. This finding agrees with the results of the historical survey. However, nothing can be determined with regard to the white sea pen's occurrence or depth range in the northern canyons, because of the lack of comparable coverage. The galatheid crab *Munida valida* has

peak densities between 100 to 200 meters in both the north and south canyons. In the northern canyons this organism's depth range extends much deeper than it does in Baltimore Canyon. This difference is probably a reflection of increased suitable substrate availability, namely the consolidated clay outcrops found at greater depths in the northern canyons.

Two organisms that do show emergence at higher latitudes are *Cerianthus borealis* and *Cancer borealis*. The large burrowing anemone *Cerianthus borealis* has peak densities between 200 to 400 meters in Baltimore Canyon and 200 to 300 meters in Lydonia Canyon. Similarly, the jonah crab *Cancer borealis* has peak abundances between 300 to 400 meters in Baltimore Canyon and 100 to 200 meters in Lydonia Canyon. The reasons for this emergence are unclear at this time, however, temperature has been implicated as being a factor causing faunal emergence. Interestingly, the two species that do show this pattern of emergence appear to be somewhat loosely associated, in that small individuals of *Cancer borealis* are frequently found nestled around the base of the *Cerianthus borealis* tube.

Figure 21 compares the depth distribution of the two major crabs found in these canyons, the jonah crab *Cancer borealis* and the red crab *Geryon quinquedens*. *C. borealis* is an important component of the shallow water assemblage, while *G. quinquedens* is the dominant crab in deeper water.

The depth range of *C. borealis* is between 100 to 600 meters, while the depth range of *G. quinquedens* is from 300 to greater than 1100 meters. The abundance of the red crab *G. quinquedens* is never as high as that of *C. borealis* however, its concentration in localized areas can be exceedingly high.

G. quinquedens is frequently found in areas of semi-consolidated clay where it burrows extensively, occasionally causing large tunnel-like excavations. Even though the depth ranges of both of these crabs overlap, they are rarely seen in high abundances in the same area. This may be the result of habitat differences or of competition between the two species.

Corals

Corals (primarily alcyonarians) are found in all three of the canyons surveyed, and include a wide variety of types, sizes, and growth forms. Both scleractinians (hard corals) and alcyonarians (soft corals) are seen. The scleractinians range from small delicate solitary cup corals to large anastomosing colonies. Alcyonarians range from small non-descript sea pens to massive branching colonies that are several meters in height. A taxonomic description of the more common alcyonaria found in the study area may be found in Appendix B. A description of the scleractinia encountered in this study may be found in Appendix C.

Coral distribution

Corals were seen at most of the depths surveyed in all three canyons. Of these Baltimore Canyon has the fewest corals, both in terms of number of species and their abundances (Fig. 22). Since many of the coral species are restricted to hard substrates, this finding is probably a reflection of the fact that Baltimore Canyon exhibits the least amount of exposed outcrop. The most common coral found in this canyon is the white sea pen, which is a major component of the shallow-water faunal assemblage. This coral occurs in dense patches on the east wall of the canyon. The other corals that are found in Baltimore Canyon are usually restricted to the axis. A species of the genus *Flabellum* (most likely *F. alabastrum*) and a small non-descript sea pen are found in the shallow axis between 200 to 400 meters. Similar small sea pens also occur on the west wall of the canyon in the same depth interval. Both of these corals are restricted to soft substrates. Slightly deeper, where the canyon axis constricts and bends, outcrops and talus blocks are exposed. Several corals restricted to hard substrates are found in this region. Massive colonies of the gorgonian *Paragorgia arborea* are found attached to the surface of large rock outcrops. The skeletons of some dead colonies are also seen at the base of these outcrops. Other corals found in this area include *Acanthogorgia armata*, *Primnoa reseda*, *Eunephthya florida* and *Anthothela grandiflora*.

Both of the northern canyons have considerably more diverse and abundant coral populations than are found in Baltimore Canyon. Many of these corals are attached forms, so this difference is a reflection of the greater amount of hard substrate exposed in these canyons. This indicates that the availability of suitable substrate plays a key role in determining the distribution of many of these corals.

Of the two northern canyons surveyed Lydonia Canyon has a less abundant coral population than Oceanographer Canyon. Three soft corals, one alcyonacean *Eunephthya florida* and the two gorgonians *Paramuricea grandis* and *Acanthogorgia armata*, are the most common corals found in this canyon (Fig. 23). *E. florida* is found on the east wall along the axis, between the depths of 500 to 700 meters, where it frequently occurs in heavy concentrations. Several individuals of a closely related species, *E. glomerata* observed on both the east and west walls of the canyon. *Paramuricea grandis* and *Acanthogorgia armata* are found in the axis and on the walls, with *P. grandis* being more common in the deeper part of the axis (below 800 meters). Other soft corals, occurring along the axis of Lydonia Canyon, that are restricted to hard substrates are *Paragorgia arborea* (Fig. 25d), *Primnoa reseda*, *Trachythela rudis*, and *Anthothela grandiflora*. The solitary scleractinian *Desmophyllum cristagalli* is also found on the outcrops in the deeper part of the axis and in some areas on the west wall.

Corals restricted to soft substrates are: the pennatulid *Pennatula aculeata*, found in the shallow axis and on the west wall; *Kophobelemnon stelliferum* in the axis and on the east wall; and a small unidentified seapen on the east wall and flank. The coral populations on the two flanks of the canyon are quite sparse and reflect the relative scarcity of large hard substrates in these areas.

Of the three canyons surveyed Oceanographer Canyon has the greatest abundance of corals, with large populations on the walls and flanks as well as in the axis (Fig. 24). The corals plotted on this map include those found during the historical survey. Again, this reflects the control that availability of suitable substrate has on determining the distribution of these corals. Numerous areas of hard substrate in the form of outcrops, talus and glacial erratics are found throughout this canyon rather than being mostly restricted to the axis. Again two of the most common corals are the gorgonians *Paramuricea grandis* and *Acanthogorgia armata* both of which occur throughout the canyon. Minor differences in the distribution can be noted. *A. armata* dominates the corals on the west flank and on the shallow part of the east flank, while *P. grandis* dominates deeper on the east flank and within the axis. This reflects apparent differences in the substrate requirements of these two species. *A. armata* is most common on smaller cobbles and boulders, while *P. grandis* is usually

found on large boulders or outcrops. The other corals found in Oceanographer Canyon that are restricted to hard substrates are: *Anthomastus agassizii* in the axis and on both walls; *Trachythela rudis* on the west wall; large colonies of *Paragorgia arborea* in the axis above 1000 meters; numerous individuals of the small encrusting soft coral *Anthothela grandiflora* along the axis; and the solitary coral *Desmophyllum cristagalli* throughout the axis and on the west flank. Corals restricted to soft substrates include: *Anthomastus grandiflorus* on the east flank; *Acanella arbuscula* on both walls; *Pennatula aculeata* in the deeper axis; a small sea pen *Distichoptilum gracili* on the lower east wall and in the axis; and a small non-descript sea pen on the deeper west flank.

Aside from the fact that fewer corals are found in Baltimore Canyon, there are also some other distinct differences between the coral populations in the three canyons. The dominant coral in Baltimore Canyon is a fluffy white sea pen that is restricted to soft substrates. Of the three corals most common in the two northern canyons *Eunephthya florida*, *Acanthogorgia armata* and *Paramuricea grandis* (Fig. 25a, b and c), only *E. florida* and *A. armata* are found in Baltimore Canyon. They both occur in that canyon, but are found in very reduced numbers. All three of these corals require hard substrate for attachment, thus their absence or reduced abundances in Baltimore Canyon reflect the lesser

amount of hard substrate available in that canyon. An additional factor may be that the heavy sedimentation rate in this canyon precludes large populations of these corals as a result of sediment loading, such that it would be harder for them to survive.

The coral populations of the two northern canyons are more similar in terms of species composition. However, on the whole Oceanographer Canyon has higher concentrations of corals and they are not as restricted to the axis of the canyon as they are in Lydonia Canyon. The three most common corals are *Eunephthya florida*, *Paramuricea grandis* and *Acanthogorgia armata*. Figure 26 shows the abundance of these three corals in Oceanographer and Lydonia Canyons. Abundances of *E. florida* are highest in Lydonia Canyon, with this species dominating the coral population in the shallower part of the axis between 500 to 800 meters. The other two corals *P. grandis* and *A. armata* are more common in Oceanographer Canyon. Reasons for these differences are not known at this time. Of these three corals only *P. grandis* is not found in Baltimore Canyon. This agrees with the results of the historical survey where *Paramuricea grandis* was restricted to the northern part of the study area.

Coral communities

Principal components analysis of the coral fauna was only attempted for Lydonia and Oceanographer Canyons, because coral

occurrences are very limited in Baltimore Canyon. In both of these northern canyons the coral populations exhibit very little cohesive structure. Only 39% of the data variance in Lydonia Canyon was explained by eleven species, nine monospecific and one dispecific end-members. In Oceanographer Canyon 63% of the data variance was explained by ten monospecific end-members. The coral fauna in most of the areas surveyed tends to be dominated by one of these end-members. This means that the distributions of most of the coral species are controlled by different factors. However, this phenomenon may also be an artifact of a problem encountered during the survey, namely the disjointed photographic coverage in many of the areas having rough terrain. Thus, some of these corals may consistently co-occur in many of the areas, but spotty coverage in these areas would not necessarily reflect this.

Faunal associations

Basically two patterns of symbiosis exist between animals, facultative and obligatory. In facultative associations the organisms have the "faculty" to enter into a symbiotic relationship but need not do so to survive. In obligatory associations one of the organisms needs to enter into a symbiotic relationship in order to survive. There are also three major types of interactions between symbionts. Mutualism means that both animals derive benefit from the association. Commensalism

benefits one of the symbionts without affecting the other. Parasitism benefits one of the symbionts at the expense of the other one.

Several types of associations were observed in this survey, only one of which could be considered purely parasitic. This was the infrequent occurrence of large parasitic copepods on the deep-sea eel *Synaphobranchus kaupii*. Undoubtedly, there were many more examples of parasitism that were not discernable on photographs because many parasites are quite small. Of the other associations seen most could be considered to be commensal. However, it is difficult to distinguish between commensalism and mutualism on the basis of photographs, since little is known about the natural history of many of the organisms. Additionally, many associations are manifested behaviorally and require direct visual observation over a period of time.

One of the most common associations was the frequent occurrence of shrimp on the larger soft corals such as *Paragorgia arborea*, *Paramuricea grandis*, *Primnoa reseda* and *Eunephthya florida*. A possible relationship between the shrimp and the corals could be that the shrimp clean the surface of the coral, preventing sediment loading, and thereby gaining nutrition from the detritus. Or the shrimp could be afforded protection from predation by hiding within the colony. Another possibility is that the shrimp are merely preying on

the polyps of the corals. Or the association could be a combination of these interactions. Shrimp were also frequently seen on hydroids and sponges.

Two other associations with corals were noted. One is the occurrence of the ophiuroid *Asteronyx loveni* in colonies of *Paramuricea grandis*. This association appears to be obligatory in that no free-living *A. loveni* were ever seen. The ophiurid could merely be using the coral colony as a substrate such that it can be suspended in the water column for feeding or it might actually prey on the coral polyps. Another possibility is that it uses the coral as protection from predation. The other association involves *P. grandis* and the anemone *Actinauge verilli* which is sometimes found attached to the coral. Whether this association is obligatory is not known.

Other associations that were noted are between juvenile crabs and fish and the large anemones found in shallow water. These anemones are *Cerianthus borealis*, *Bolocera tuediae*, *Actinoscyphia saginata* and the large white anemone found in Baltimore Canyon. The small crabs and fish appear to be utilizing the base of the anemones for protection. Two species of crabs *Cancer borealis* and *Bathynectes superba* and the rosefish are most commonly seen in this association. This relationship most frequently occurs between *Cancer borealis* and *Cerianthus borealis*. A small galatheid crab was also seen crawling on the

surface of the large white anemones in Baltimore Canyon.

Two types of associations where organisms attach onto crabs were also noted. A facultative relationship exists between the red crab *Geryon quinquedens* and a small white barnacle that attached to its carapace and legs. Frequently, individuals of *G. quinquedens* had as many as 40 of these barnacles attached to them. It is assumed that the barnacles just utilize the crab carapace as a hard substrate, since both organisms can exist without this relationship. The other association, between zoanthids and the hermit crab *Parapagurus* sp., is obligatory. The crab needs the zoanthid to provide protection for its soft carapace, much as different species of hermit crabs use discarded gastropod shells. The zoanthid may also benefit by obtaining food scraps from the crab.

Comparison of towed camera-sled and submersible

A comparison of the relative efficiency of the two photographic survey techniques used in the study is of particular interest for several reasons. It helps to elucidate the inherent biases of these techniques and thus allows for better determination of the suitable method to use for specific purposes. This is important because of the cost discrepancy between these methods. Also by utilizing the best technique for a particular problem

research effort can be optimized. Additionally, such a comparison might lead to directed improvement of these methods to increase their effectiveness as a survey tool.

Due to the necessity of avoiding obstacles with the camera-sled, it would be suspected that the camera-sled tends to underestimate coral abundances. The proximity of the camera to the bottom and its angle of incidence with respect to the bottom could also produce different results. The external camera on ALVIN is mounted farther above the bottom and is positioned at a higher angle of incidence than the camera on "Cheep Tow". As a result the camera on "Cheep Tow" views a larger area of the bottom per frame. However, this configuration causes the amplification of errors in estimates of area viewed when the camera's position deviates from horizontal with respect to the bottom. Additionally, some of the smaller taxa are more readily seen in the foreground of "Cheep Tow" photographs because of their closer proximity to the camera. Another factor might be differences in the response of motile spibenthos to the two systems. One bias that should not be ignored is the relative difference with regard to randomness between the two techniques. The camera-sled is operated from a surface vessel with little informational feed-back about the area being surveyed. The submersible, on the other hand, is operated under in situ conditions and may reflect biases created by the investigators

controlling its track.

A comparison of the results obtained by these two survey methods is possible for several areas in Oceanographer Canyon where the camera-sled track coincided with the location of previous ALVIN dives. A close examination of Figure 11 shows that in most areas there are marked differences in terms of faunal composition between the results obtained by these two methods. The most apparent discrepancy is that the towed camera-sled does indeed underestimate the abundance of corals. This difference is greatest in areas of high relief when the camera-sled is towed across bathymetric contours rather than along them. A closer examination of the species shows that most of them are taxa that are restricted to hard substrates.

On the west wall of Oceanographer Canyon the fauna surveyed with ALVIN (circles with stars) consistently had higher proportions of corals, than that surveyed by "Cheep Tow". The corals *Anthomastus agassizii*, *Paramuricea grandis* and *Acanthogorgia armata* frequently composed more than half of the epifauna surveyed by ALVIN. The abundances of these corals was markedly reduced in the photographs taken by "Cheep Tow." The results of the survey done by camera-sled do show that these corals are present in that area, but it does not reflect their true abundances or relative proportion of the fauna. One taxa consistently underestimated by the ALVIN

survey was the small shrimp that is very common in this area.

In some places in the axis of the canyon the results obtained with ALVIN and "Cheep Tow" are very similar. In one area between 1500 and 1600 meters the dominant taxa in both surveys were fish. However, slightly further up the axis, within the same depth interval, two corals *Desmophyllum cristagalli* and *Anthomastus agassizii* comprised more than 60% of the fauna surveyed by ALVIN. These corals are restricted to hard substrates and were very common on the outcrops and numerous talus blocks found along the sides of the axis. Slightly deeper, between 1700 and 1800 meters in the relatively flat axis of the canyon, comparable coverage was obtained using both survey methods. Interestingly, the results are remarkably similar in both the types of fauna seen and in their absolute abundances. *Ophiomusium lymani* accounted for 77% of the total fauna surveyed by both the camera-sled and ALVIN. The two techniques gave faunal densities of 253 and 244 individuals per 100 m² respectively. The major difference between the two methods was that 16% of the fauna surveyed by camera-sled was composed of the coral *Pennatula aculeata*, while the corals seen in the ALVIN photographs were *Anthomastus agassizii*, *Paramuricea grandis*, *Desmophyllum cristagalli* and *Distichoptilum gracile*. This discrepancy is probably a reflection of the fact that the ALVIN dive track followed the outcrops along the side of the axis while the camera-sled was

towed across the axis.

It is apparent that for a survey of corals and other hard substrate fauna the submersible has many advantages. However, a submersible is also much more expensive and cannot quickly survey as large an area as can a camera-sled. The ideal methodology for a large scale survey of the type attempted in this study would be to initially survey an area using a camera-sled that can be towed in a flying mode. The results of that survey could then be used to identify areas that warrent closer study by a submersible.

CONCLUSIONS

The field survey largely substantiates and expands the findings of the historical survey. Canyons afford unique habitats for their faunal constituents by providing a variety of substrate types and possible nutrient enrichment. This heterogeneous environment allows many species and various trophic types to coexist. In shallow water (100-400 m) canyon faunal assemblages are similar to those found on the slope. The major difference between canyon and slope habitats manifests itself in the middle depth range (400-1100 m). Within this depth range the fauna of the slope is heavily dominated by fish, while the fauna in canyons is frequently dominated by small shrimp, corals and sponges. This is a

direct result of the environmental heterogeneity, in terms of substrate variability, provided within canyons. This is particularly true of canyons that have substantial exposures of hard substrate and thus provide many sessile species with suitable attachment sites. Canyons that do not have much exposed outcrop tend to resemble slope environments and this is reflected by their faunal constituents.

In general, the shallow-water fauna (100-400 m) of canyons does not differ markedly from that of the slope, with the most common species being similar in both habitats. The shallow water species also have narrower depth ranges in both environments than do the deeper water ones. It is not known whether this is due to competition, availability of suitable substrate, temperature or barometric pressure tolerances. There is a tendency for the slight emergence of some of these species with increasing latitude.

The greatest difference between slope and canyon habitats is seen in the mid depth range (400-1100 m). The slope tends to be homogeneous with regard to substrate, while the canyons offer a variety of different types. In determining the difference between the fauna found in the two environments, hard substrate appears to be the most important. It provides attachment sites for numerous sessile filter-feeding organisms, and spatial heterogeneity for many small shrimp. The fauna of the slope, on the other hand, is heavily dominated by the crab

Geryon quinquedens and two types of demersal fish, rattails and the eel *Synaphobranchus kaupi*. Gradation in this difference is seen by a closer examination of the mid-depth fauna in the three canyons studied. Of these canyons Baltimore Canyon most closely resembles slope habitats, in that this canyon evidences the least amount of substrate variability. This is reflected in the fauna of the mid-depth range which is dominated by the same three species that are also abundant on the slope. In the northern canyons sessile filter-feeders frequently are important constituents of the fauna at these depths, and thus *G. quinquedens*, *Synaphobranchus kaupi* and rattails are not as dominant.

Community analysis identified a rather variable shallow-water assemblage (100-400 m) and a less variable deeper one. This is similar to the trends seen on the slope and was the most pronounced in Baltimore Canyon. The fauna of the mid-depth region (400-1100 m) of the northern canyons tended to be somewhat more variable. Principal components analysis did not identify any cohesive assemblages of species. The results indicate that the majority of the dominant species found in the canyons are independently distributed. This means that these species are responding to different environmental parameters.

ANTICIPATED ENVIRONMENTAL IMPACT OF
OCS RESOURCE DEVELOPMENT

Some of the environmental parameters responsible for variations in epifaunal distribution are now known. However, knowledge concerning the causative agents of many of the variations observed is still far from complete. The patchy distribution of many of the major faunal components precludes accurate prediction as to their location and abundance. This problem is largely due to the paucity of correlative fine scale environmental information concerning the physical and chemical processes of slope and canyon habitats. The lack of this information substantially hampers meaningful interpolation from one area to another. These factors combine to make assessment of the environmental impact of resource development premature.

The results of the field program substantiate the findings of the historical survey. Canyon habitats are unique in that they provide suitable environmental parameters to support large populations of filter-feeders, namely corals and sponges. As a result resource development that alters the characteristics of the water column in the vicinity of large canyon systems could be detrimental to their faunal assemblages. Generally, filter-feeders are sessile and have precise substrate requirements. Thus, environmental change that affects substrate characteristics could also prove to be detrimental.

Particularly relevant to this are some findings by Grigg (1965) concerning the specificity of substrate type and texture requirements of the black coral *Anthipatharia grandis*. In studying the distribution of this organism he concluded that larval individuals of this coral settle only on substrates that have some CaCO_3 on their surface. Small irregularities or depressions on the surface of the rock were also found to be important in determining larval settlement success. Hard corals also initially settle on hard substrates, subsequently some species break off and lie on the surface of sediment. As a result, if increased sedimentation coats the hard substrates with even a fine layer of loose material, and if this is not removed by currents, the settling success of coral larvae could be substantially altered.

A comparison of the filter-feeding populations found in the three canyons surveyed elucidates some of the problems that may be encountered as a result of resource development. Baltimore Canyon has a relatively high sediment load in its water column and not much exposed hard substrate when compared to Lydonia or Oceanographer Canyons. As a result Baltimore Canyon's population of filter-feeders is sparse and not very diverse. Additionally, dead parts or complete colonies of some coral such as *Paragorgia arborea* were frequently noted in this canyon. This mortality could well be the result of a high sedimentation rate causing fouling of these colonies. Another

factor could be the abrasive effect of suspended inorganic particulate matter, which would be expected to be substantial in areas of high current activity (Grigg, 1965). Grigg found that colonies of *Antipatharia grandis* were very susceptible to the deleterious effect of suspended particulate matter in areas of high currents. Thus, increases in the amount of suspended inorganic particulate matter could be harmful to corals as a result of abrasion in areas of strong currents, as well as sediment loading in tranquil areas.

This conclusion should not be surprising if viewed in terms of the biology of these organisms. Their simple morphological structure results in direct exposure of tissue to the surrounding environment. Thus, the rubbing against or the accumulation of material on corals kills the tissue beneath it. Another mechanism by which sediment load can have deleterious effects on corals is by stimulating mucous production. Experiments with shallow water corals show that stressed corals increase mucous production in an attempt to remove fouling material (Lewis and Price, 1976). Soft corals are particularly sensitive to sediment loading if currents are different from what they are usually exposed to or if an increased amount of particulate matter is added to their environment (Bayer, personal communication). The corals initially contract and then increase their mucous production to rid themselves of the fouling material. After several

weeks of cycles of contraction and excess mucous production the coral eventually slough off their tissue layer and die. This excess mucous also provides a suitable habitat for bacteria, many of which are harmful to the coral (H. W. Ducklow, personal communication). In fact, these bacteria frequently respond to stress on the host coral by growing in higher concentrations (Ducklow and Mitchell, 1979). Additionally, alterations to the water column that affect its nutrient flux, such as causing a decrease in primary productivity, could increase coral mortality by decreasing the available nutrients.

At present it is necessary to obtain a more comprehensive understanding of the environmental processes that affect the epifaunal components of the continental margin on both the slope and in the canyons. Only then will accurate assessments of the impact of resource development be feasible. This study has identified some of the possible mechanisms by which resource development could be deleterious. But at present these conclusions should only be viewed as exceedingly tentative.

SUMMARY

For the field study three major canyons were surveyed using a towed underwater camera system. These were Baltimore, Lydonia and Oceanographer Canyons. The depths surveyed were 100 to 1100 meters in Baltimore Canyon, 100-900 meters in

Lydonia Canyon and 400 to 1800 meters in Oceanographer Canyon.

1. Baltimore Canyon has the least amount of substrate variability, with most outcrops being restricted to the axis, Lydonia and Oceanographer Canyons both have quite a variety of substrate types, with outcrops not limited to the axis. Additionally, large outcrops of consolidated clay and numerous glacial erratics are also present in these latter two canyons.

2. Corals are found in all three canyons. Baltimore Canyon has the lowest concentration and least diverse coral assemblage, which is dominated by a small white sea pen. Lydonia Canyon has a considerably higher concentration of corals, the most abundant of which is *Eunephthya florida*. Oceanographer Canyon has the largest and most diverse coral population, with *Paramuricea grandis* and *Acanthogorgia armata* being the dominant species.

3. Canyon faunal assemblages are variable in shallow water (100-400 m). The shallow water species have a more restricted depth range. Of the three canyons studied Oceanographer Canyon has the most variable deep water fauna (400-1800 m).

4. Faunal densities are high in shallow water and decrease with increasing depth. Below 1700 meters faunal densities increase again. The high densities in shallow water are largely due to anemones and the quill worm

Hyalinoecia artifex. The deeper fauna is dominated by the red crab *Geryon quinquedens* and two types of demersal fish, the eel *Synaphobranchus kaupi* and rattails. Below 1700 meters the brittle star *Ophiomusium lymani* predominates.

5. The mid-water depths (400-1100 m) in Lydonia and Oceanographer Canyons have a more variable fauna. They both support large populations of shrimp and filter-feeders, namely corals and sponges. This attests to the environmental heterogeneity of these canyons. It also supports the hypothesis that canyons are areas of nutrient enrichment.

6. Community analysis indicates that the majority of the dominant faunal constituents of canyon assemblages are independently distributed. This implies that the environmental factors controlling each species are different.

7. The results of this study agree with and amplify on the findings of the historical survey. Canyon habitats are unique and support a large variety of fauna. However, accurate assessment of the environmental impact of resource development would at this point be premature. Needed for this are correlative fine scale studies of the interaction between the biological, physical and chemical processes of the continental margin.

Baltimore Canyon

Baltimore Canyon is one of the mid-Atlantic canyons. Of the three canyons surveyed it most closely resembles slope habitats and has the least amount of exposed outcrops. This canyon is an area of net sediment accumulation, with fine-grained sediment on the walls and outcrops mostly restricted to the axis. Overall, Baltimore Canyon affords a rather homogeneous environment in terms of variability of available substrate types. The faunal constituents reflect this homogeneity by closely resembling the fauna found at comparable depths on the slope. This is particularly evident in the sparse populations of corals and other filter-feeding organisms found in this canyon.

- (1) Faunal density is high between 100 and 400 meters.

This is due mainly to the high concentration of anemones between 100 and 300 meters and the quill worm *Hyalinoecia artifex* between 300 and 400 meters. Below 400 meters the faunal density is uniformly low.

- (2) The major faunal constituents resemble those found in slope habitats. The shallow-water assemblage (100-400 m) is variable and consists of *Munida valida*, *Cancer borealis*, a fluffy white unidentified sea pen, *Cerianthus borealis* and *Hyalinoecia artifex*.

Between 400 and 1100 meters rattails, *Synaphobranchus kaupi* and *Geryon quinquedens* dominate the fauna.

- (3) In terms of trophic types the shallow-water fauna is variable, being composed of predators, scavengers and filter-feeders. Below 400 meters larger scavengers and predators dominate the fauna.
- (4) The coral populations in this canyon are the least diverse and abundant of the three canyons surveyed. The dominant species was a fluffy white unidentified sea pen that occurred between the depths of 100 to 300 meters. Other coral species found in the canyon are *Flabellum alabastrum*, *Paragorgia arborea*, *Primnoa reseda* and *Eunephthya florida*.
- (5) One unique area in this canyon was identified. A deposit of large boulders on the middle west wall provided suitable substrate for a very high concentration of large white anemones. Many other organisms were also found in this area, particularly rosefish and several species of crabs.

Lydonia Canyon

Lydonia Canyon is one of the north-Atlantic canyons surveyed in this study and is located off Georges Bank. This

canyon exhibits a more complex pattern of substrate distribution and has a greater amount of exposed hard substrate when compared with Baltimore Canyon. Lydonia Canyon is small and has a narrow axis with steep walls. In general this canyon appears to be an area of active erosion. Fine-grained sediment predominates on the walls and along the thalweg. Rock outcrops are mainly restricted to the axis with occasional exposures on the walls. Glacial erratics are abundant on the east flank of this canyon and are present in reduced numbers on the west flank. The variety of substrates found in Lydonia Canyon provide a heterogeneous environment capable of supporting large populations of corals and other attached fauna. As a result the fauna below 400 meters frequently differs from that commonly found on the slope.

- (1) Faunal density is uniformly high between 100 and 400 meters and is attributable to high concentrations of anemones and *Hyalinoecia artifex*. Below 400 meters faunal density is uniformly low.
- (2) The major faunal constituents differ from those commonly found in slope habitats. The shallow-water assemblage (100-400 m) is variable and is dominated by *Munida valida*, *Cerianthus borealis*, *Bolocera tuediae*, a small unidentified encrusting anemone and *Hyalinoecia artifex*. Between 400 and

1000 meters the fauna is frequently dominated by shrimp, and occasionally by *Geryon quinquedens* and *Synaphobranchus kaupi*.

- (3) In terms of trophic types the fauna of Lydonia Canyon differs from that found in Baltimore Canyon in the middle depth range. The shallow water fauna is again composed of a variety of trophic types. Below 400 meters a higher proportion of the fauna is composed of filter-feeders, namely various species of corals and sponges.
- (4) The coral populations in Lydonia Canyon are diverse and abundant. *Eunephthya florida* is the most abundant coral found in this canyon and is common on the east wall along the axis. *Pennatulā aculeata* is found in quite high concentrations in the shallower part of the axis (around 500 m.). Other common corals found in this canyon are *Paramuricea grandis*, *Acanthogorgia armata* and *Paragorgia arborea*. Most of the corals found in this canyon are species that are restricted to hard substrates.

Oceanographer Canyon

Of the three canyons surveyed Oceanographer Canyon exhibited the highest degree of substrate variability. It

is a large deeply incised canyon with steep walls and is located off Georges Bank. The canyon walls and flanks consist of a fine-grained substrate with extensive exposures of rock and consolidated clay, while the walls along the thalweg consist mainly of rock outcrops. Large talus blocks are common in the axis of Oceanographer Canyon and numerous glacial erratics are found on the east flank. The extensive exposure of outcrops and numerous glacial erratics indicate that this canyon is an area of contemporary erosion. The heterogeneity of this canyon is high and this is reflected in the fauna, with corals and sponges comprising a substantial proportion of the fauna. As a result the dominant fauna found in Oceanographer Canyon differs substantially from that commonly found on the slope.

- (1) Faunal density is moderately low throughout most of the depths surveyed in this canyon (400-1600 m). Between 1700 and 1800 meters faunal density is quite high due to the presence of the ubiquitous ophiurid *Ophiomusium lymani*.
- (2) The major faunal constituents of the middle depth range (400 to 1100 m.) are shrimp and sponges. Corals are also quite common in this depth range. Below 1100 meters corals, shrimp and sponges again are common constituents of the fauna. Other dominant

taxa include rattails, *Synaphobranchus kaupi* and *Ophiomusium lymani*.

- (3) As was found in Lydonia Canyon the fauna of Oceanographer Canyon is composed of a variety of trophic types throughout the depth range surveyed. Again sessile filter-feeders such as corals and sponges comprise a substantial proportion of the total fauna. Deep in the canyon axis the deposit-feeding ophiurid *Ophiomusium lymani* predominates.
- (4) Both hard and soft substrate corals are common in Oceanographer Canyon. Two gorgonians, *Paramuricea grandis* and *Acanthogorgia armata*, are the most abundant corals found in this canyon. Other common corals include *Anthothela grandiflora*, *Anthomastus agassizii*, *Desmophyllum cristagalli*, *Distichoptilum gracile* and *Pennatula aculeata*.

RECOMMENDED ADDITIONAL STUDIES

A more thorough elucidation of the factors controlling epifaunal distribution is recommended. This study should be directed towards a better understanding of the interactive roles that biological, physical and chemical processes play in determining the distribution of the epifauna. Many of the major faunal components identified in the present study are patchily distributed, as is evidenced by such highly localized

populations as the anemone field found on the west wall of Baltimore Canyon. This faunal heterogeneity makes extrapolation from one area to another rather tentative. Based on a knowledge of the substrate characteristics of an area it is possible to predict what fauna might be there. However, at this point it is impossible to make such a prediction with any degree of certainty. Of particular importance in achieving this goal factors other than descriptive substrate characteristics must be identified. Some of the factors that might warrant further examination are: detailed substrate composition, nutrient flux, sedimentation rate, long range current dynamics and temperature fluctuations.

Such a study should be divided into several stages. The initial phase should be to create a detailed bathymetric and geologic mapping of a particular area of interest. The results of the first phase and our present study could then be utilized to predict what faunal constituents might inhabit that area and also where they would be located. Sea-floor photography with a towed camera sled should then be made to test these predictions. Tests of the predictions are important in identifying gaps in our understanding of the factors controlling epifaunal populations and their distribution. Areas of particular interest or deviation from the predictions should then be studied in detail to elucidate some of these factors. The optimum sampling technique for this phase would

be a manned submersible. This technique allows accurate location of samples with relation to each other, such as are needed to determine the interaction of biotic components with their physical environment.

The experience gained during the present study helps to identify some of the technical considerations that should be taken into account in future studies. Near bottom side-scan sonar would allow for detailed mapping of substrate bedforms and layering characteristics, such that outcrops, scars, slump deposits and zones of winnowing could be discriminated. The sub-bottom profiling should be high resolution using sound sources of 2 to 5 kHz. The navigational capabilities need to be as accurate as those used in the present field study. The towed camera-sled should be modified to allow for operation in a flying mode in areas of complex topography and high relief. Modifications should also include camera positions at higher angles of vertical incidence with respect to the bottom. This allows for a more accurate determination of aerial coverage. Such vertical incidence photography from a flying vehicle must be accompanied by an altimeter (resolution >0.5 m.) and inclinometer (resolution of 5°). To obtain more continuous coverage it is recommended that the camera-sled be towed along bathymetric contours rather than across them.

Current measurements are important and need to be made

over long intervals of time with the measuring transducers at a height above bottom that is comparable to the size of the fauna studied. Arrays of current meters would be useful for the computation of flow regimes. Correlated temperature measurements would allow for the determination of temperature fluctuations experienced by the fauna. Measurements of the concentration and composition of suspended particulate matter are also needed.

Additional studies are also recommended to fill gaps in the existing data base. The present study has identified canyons as unique in that they provide a heterogeneous environment for many of their faunal constituents. However, comparable data on slope environments and their fauna is very sparse. Additionally, the obstacles created by lobster pot arrays prevented adequate coverage of the shallower depth intervals in the northern canyons. A better understanding of the dendritic flow patterns of canyons would also be useful in determining the dissemination of by-products of resource development.

ACKNOWLEDGEMENTS

A number of people have been very helpful in providing their time and expertise during the various phases of this project. We wish to thank the Captain of the R. V. EASTWARD Harold Yeomans, the scientific party chief Gregory Miller, and the ship's crew for helping to make the field program a success. We also wish to express our appreciation to Dennis M. Opresko who participated in the field program, provided useful background information concerning coral taxonomy, and identified the coral specimens collected. We are grateful to T. Bayer (alcyonarians), S. Cairns (scleractinians) and M. Downey (echinoderms) for identifying and providing useful background information for many of the organisms photographed and collected in the field survey. Our thanks also go to Philip Thomas of B. L. M. for his participation in the field program in terms of valuable discussions and suggestions.

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Figure 1. Map of photographic coverage in Baltimore Canyon. A solid line denotes continuous coverage, while a dashed line denotes limited coverage.

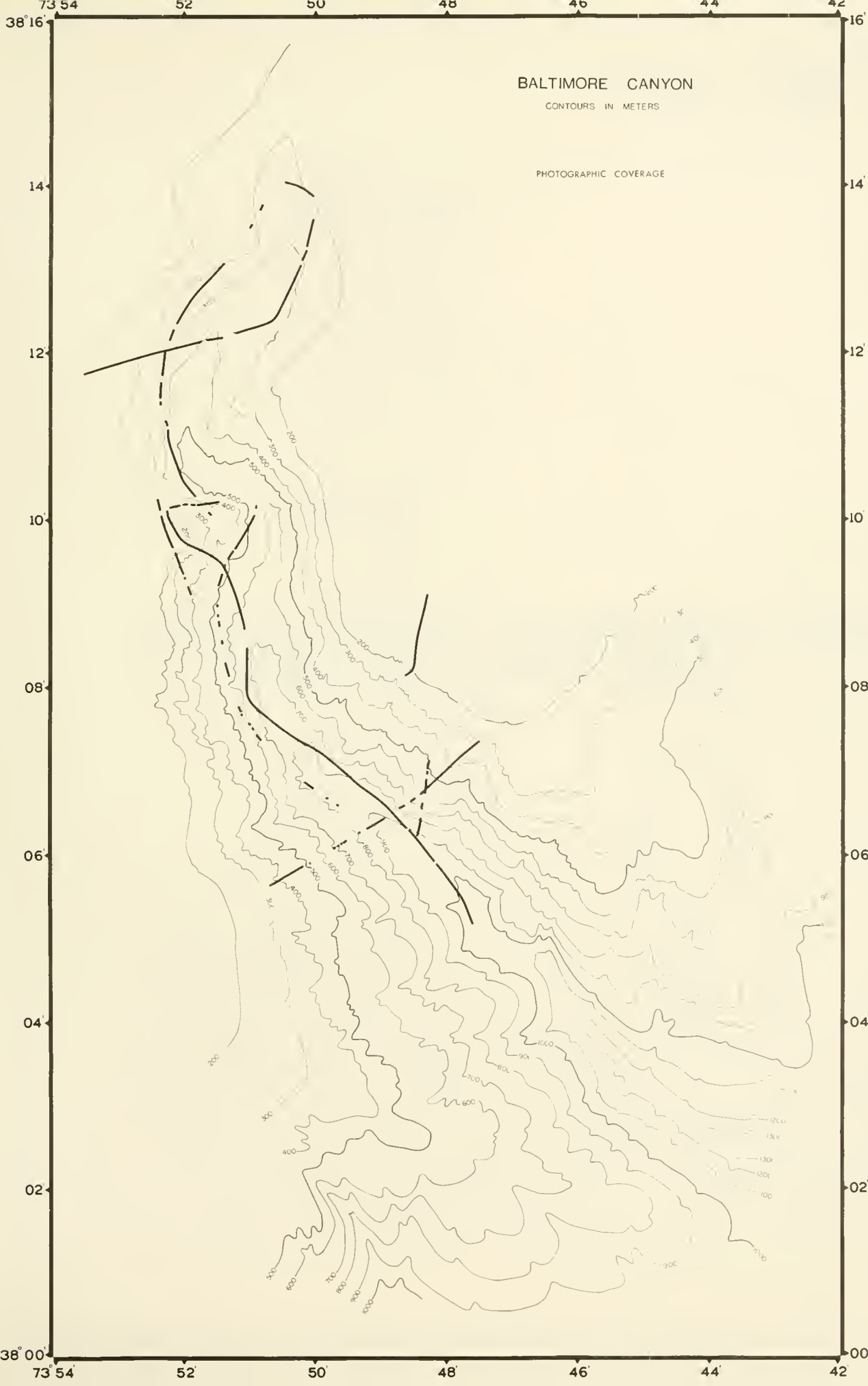


Figure 2. Map of photographic coverage in Lydonia Canyon.
A solid line denotes continuous coverage, while
a dashed line denotes limited coverage.

LYDONIA CANYON

CONTOURS IN METERS

PHOTOGRAPHIC COVERAGE



Figure 3. Map of photographic coverage in Oceanographer Canyon. A solid line denotes continuous coverage, while a dashed line denotes limited coverage.

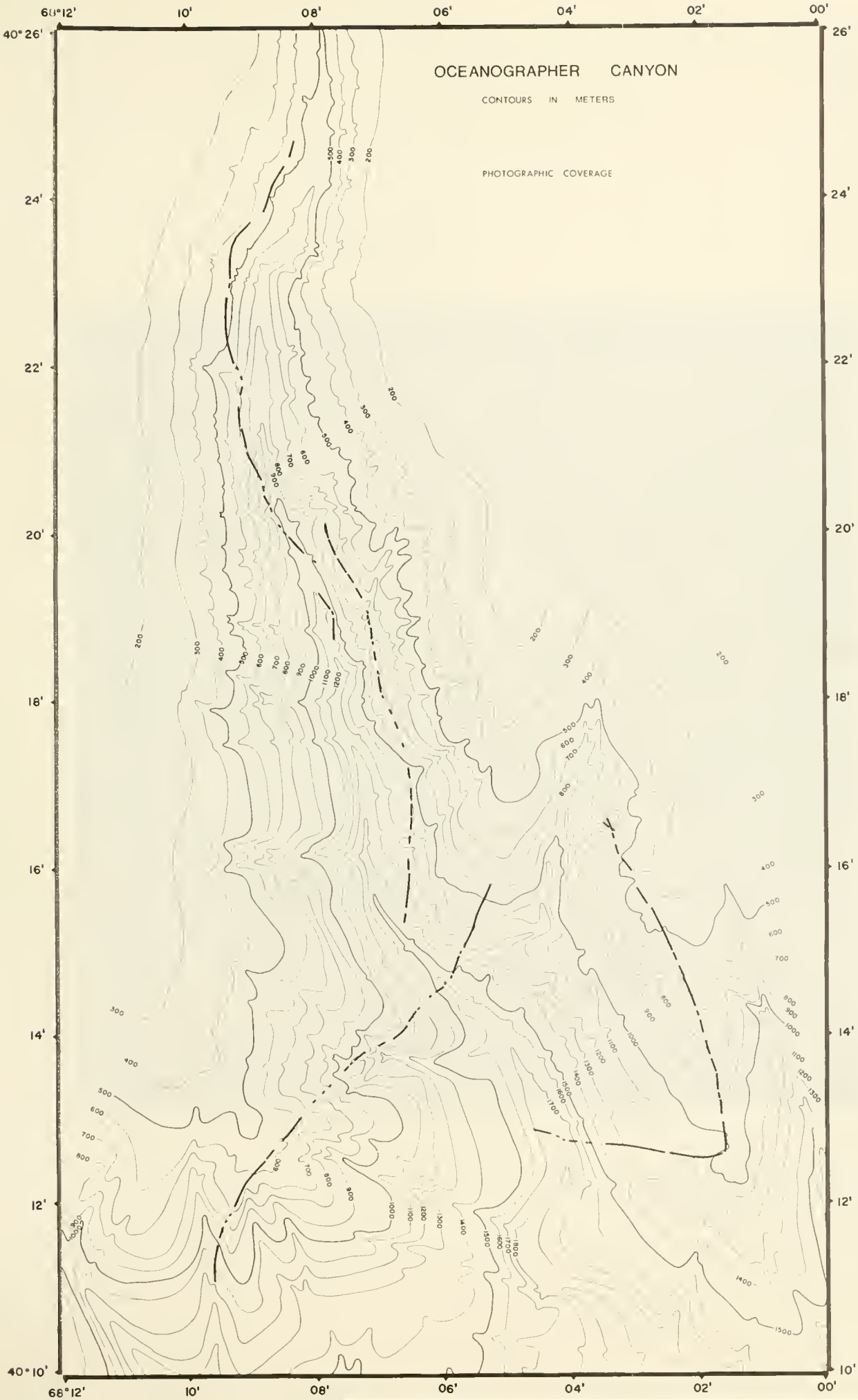


Figure 4. The camera-sled "Cheep Tow" used for the field survey.

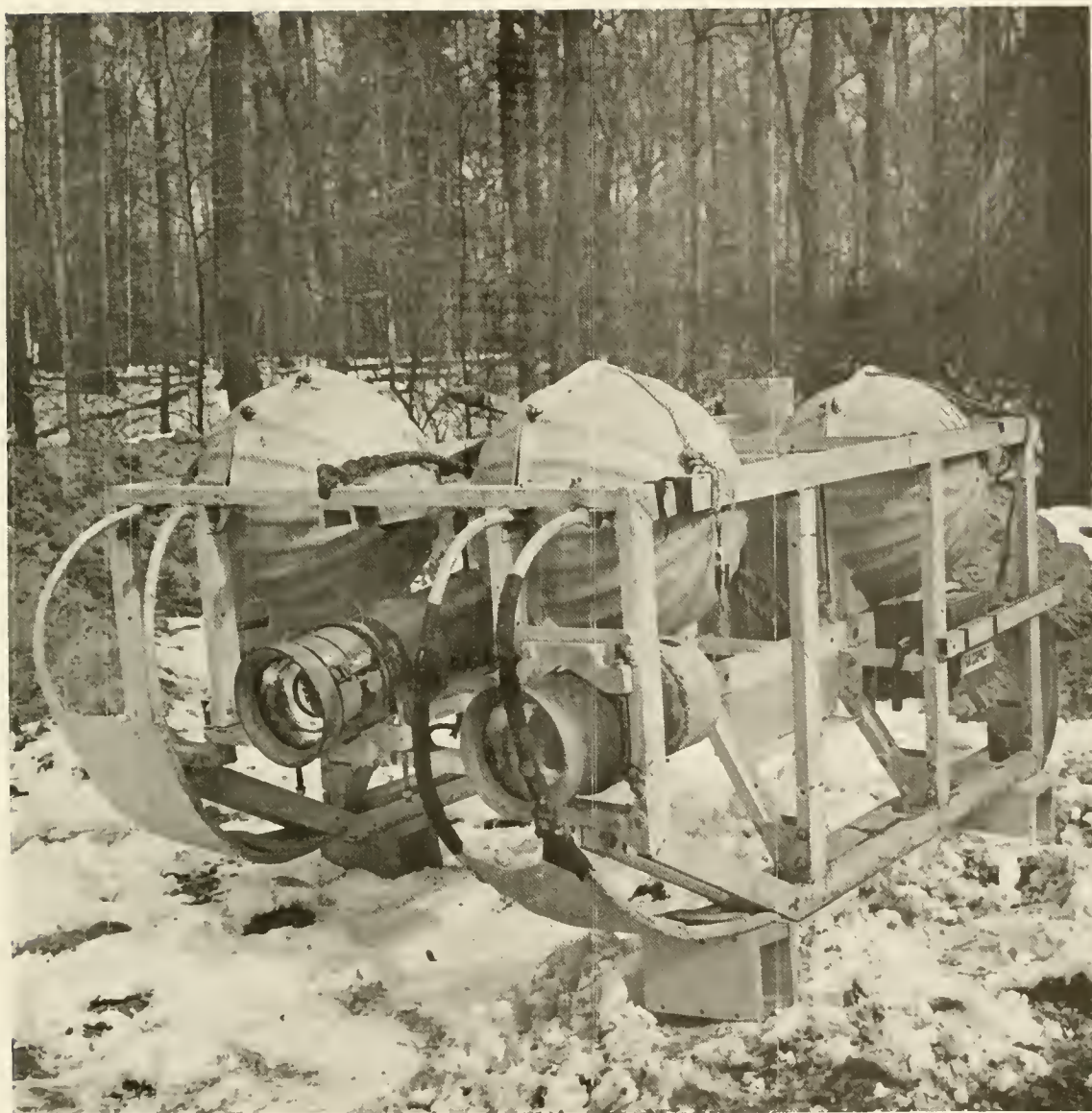


Figure 5. Histogram of the faunal density, for all three canyons, standardized to individuals per 100m^2 for 100 meter depth intervals.

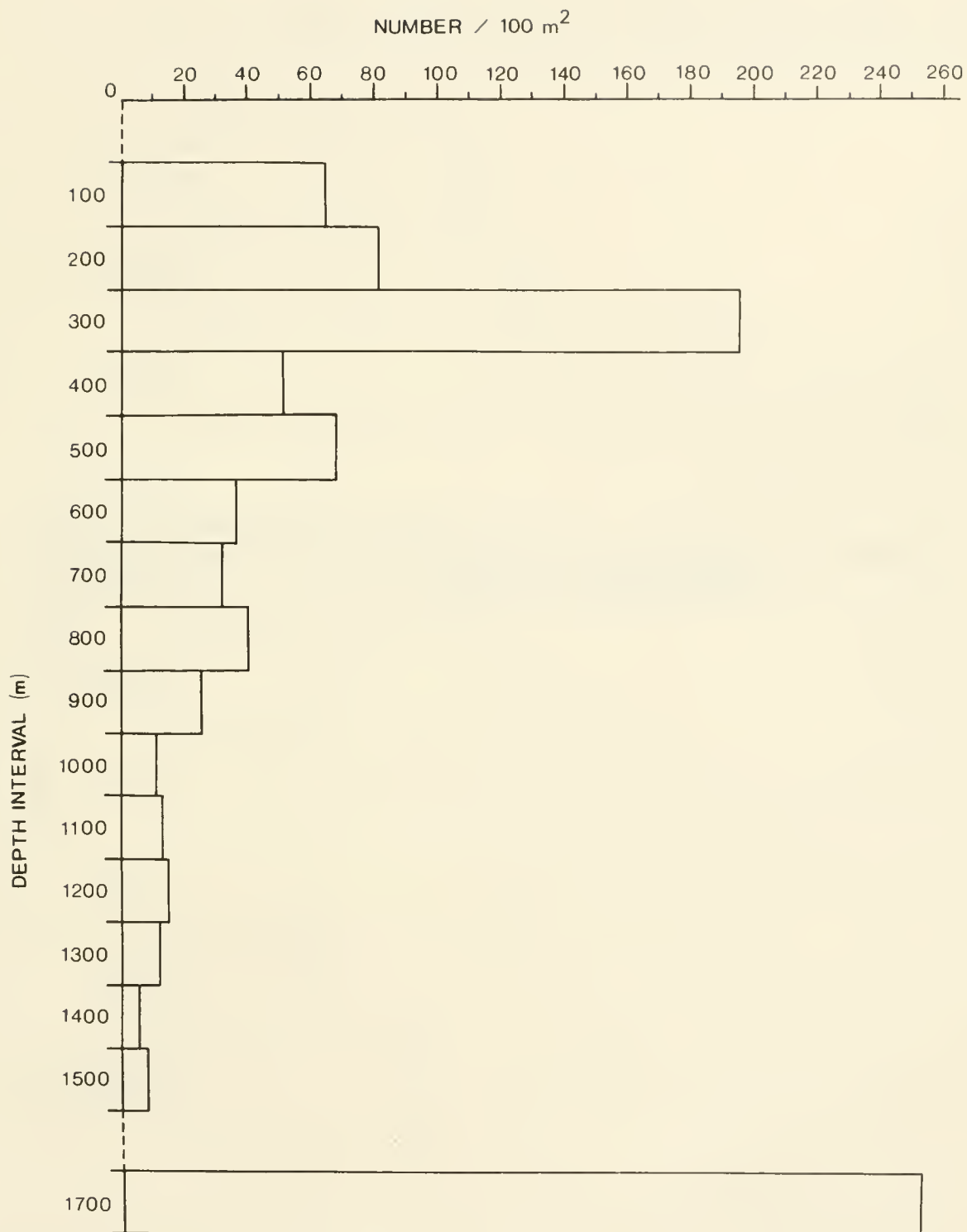


Figure 6. Histogram of faunal density in Baltimore Canyon, standardized to individuals per 100m^2 for 100 meter depth intervals.

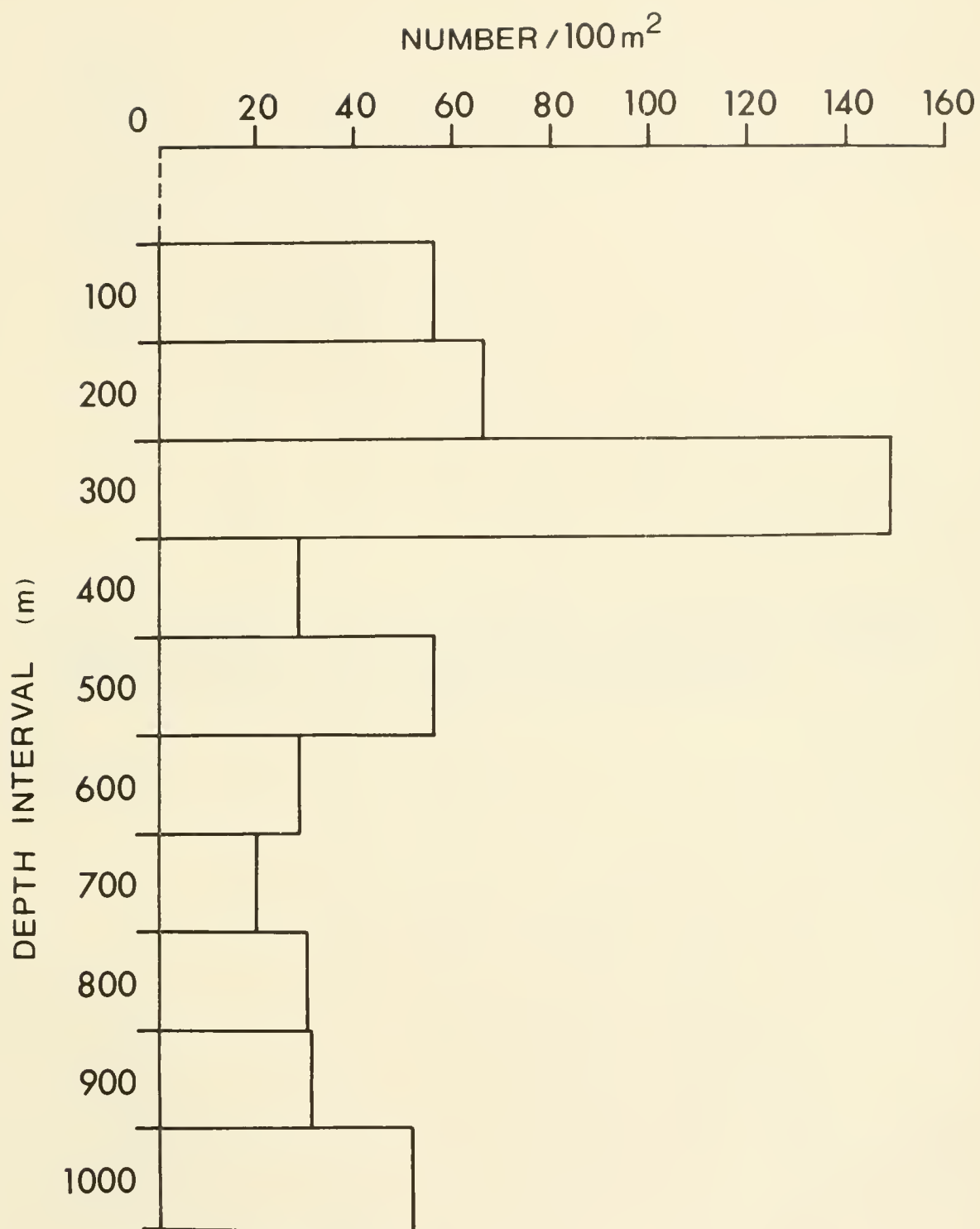


Figure 7. Histogram of faunal density in Lydonia Canyon, standardized to individuals per 100m² for 100 meter depth intervals.



Figure 8. Histogram of faunal density in Oceanographer Canyon, standardized to individuals per 100m^2 for 100 meter depth intervals.

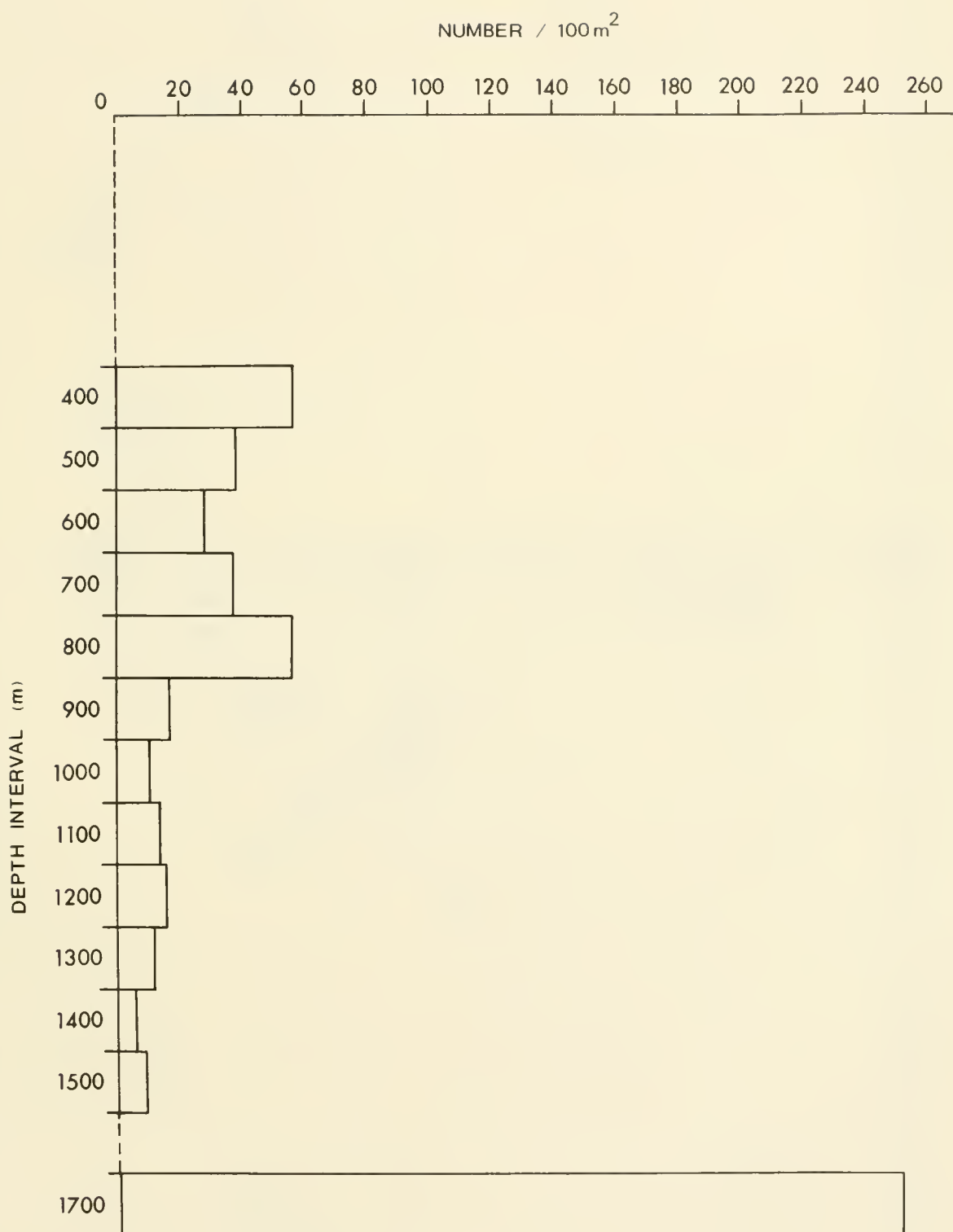


Figure 9. Map of the relative percentages of major faunal groups in Baltimore Canyon for 100 meter depth intervals.

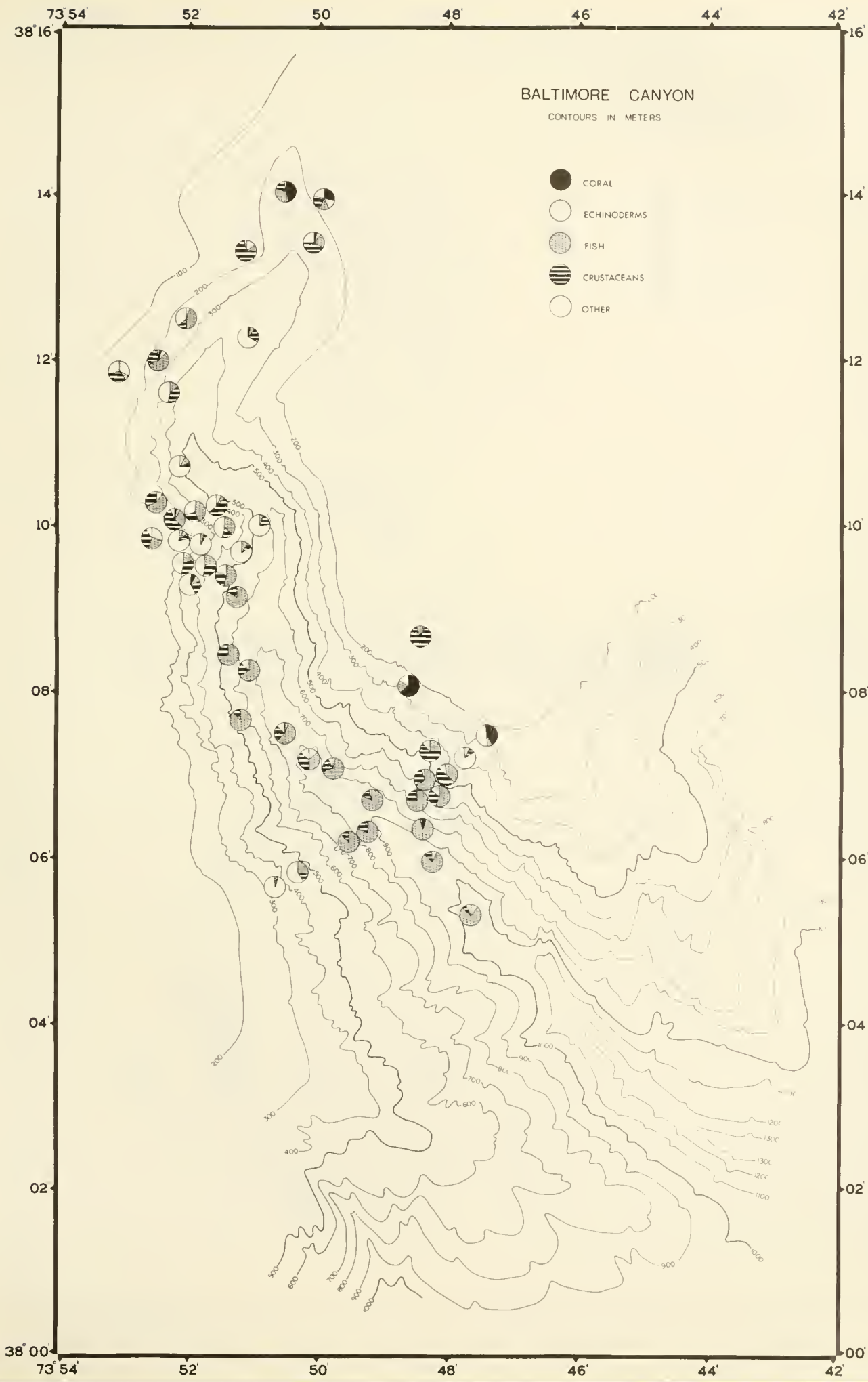

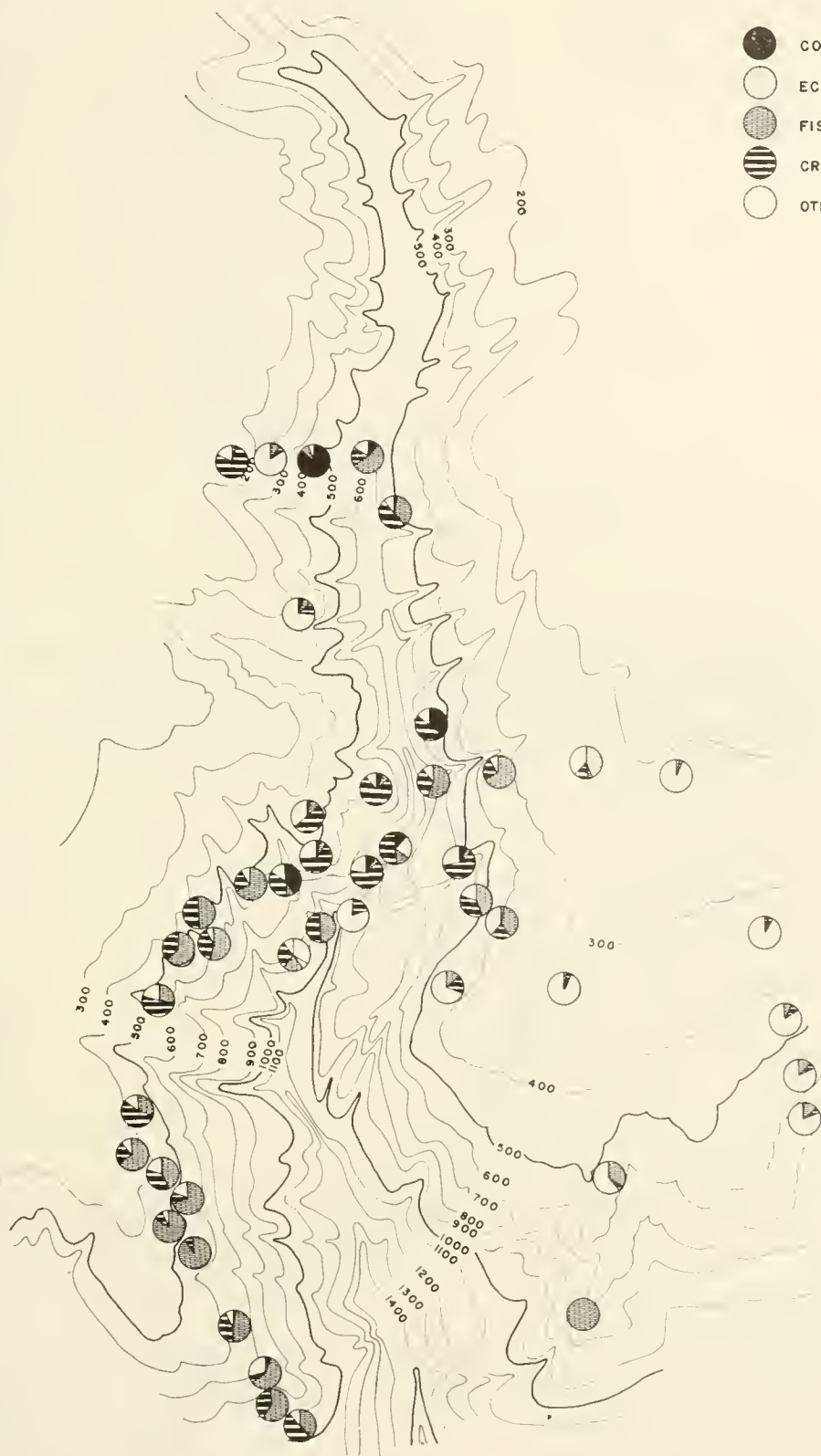


Figure 10. Map of the relative percentages of major faunal groups in Lydonia Canyon for 100 meter depth intervals.

LYDONIA CANYON

CONTOURS IN METERS

-  CORAL
-  ECHINODERMS
-  FISH
-  CRUSTACEANS
-  OTHER



67° 45' 44' 43' 42' 41' 40' 39' 38' 37' 36' 35' 34' 33'

40' 30' 29' 28' 27' 26' 25' 24' 23' 22' 21' 20' 19' 18' 40' 17'

Figure 11. Map of the relative percentages of major faunal groups in Oceanographer Canyon for 100 meter depth intervals. Circles with stars (*) represent data collected with ALVIN (historical survey-dives 779, 784 and 785).

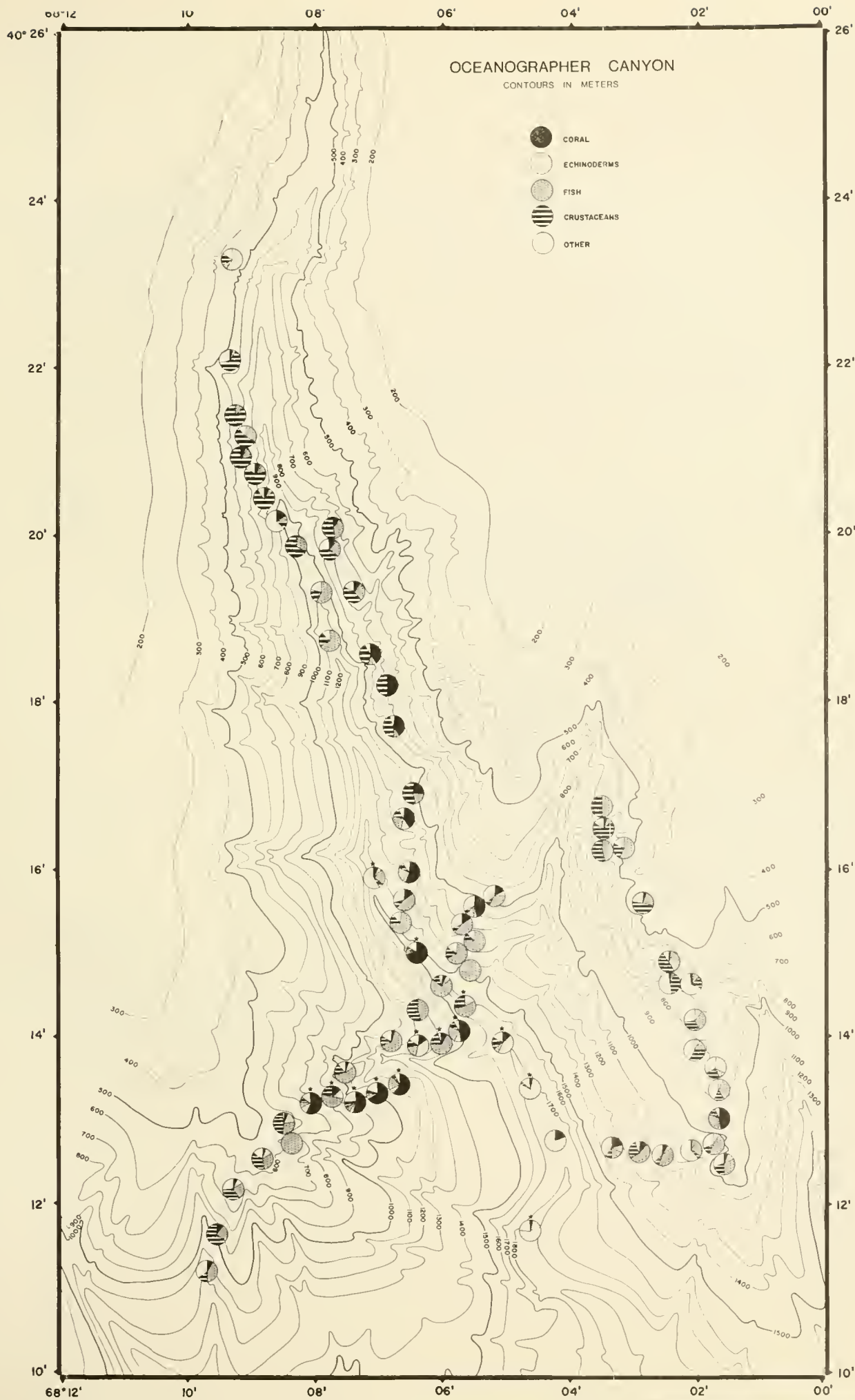


Figure 12. Cluster diagram of the percent species similarity for various areas in Baltimore Canyon. Species and taxa identified on the joins represent dominant fauna in those areas.

A = axis
UW = upper west wall
MW = middle west wall
LW = lower west wall
UE = upper east wall
ME = middle east wall
LE = lower east wall

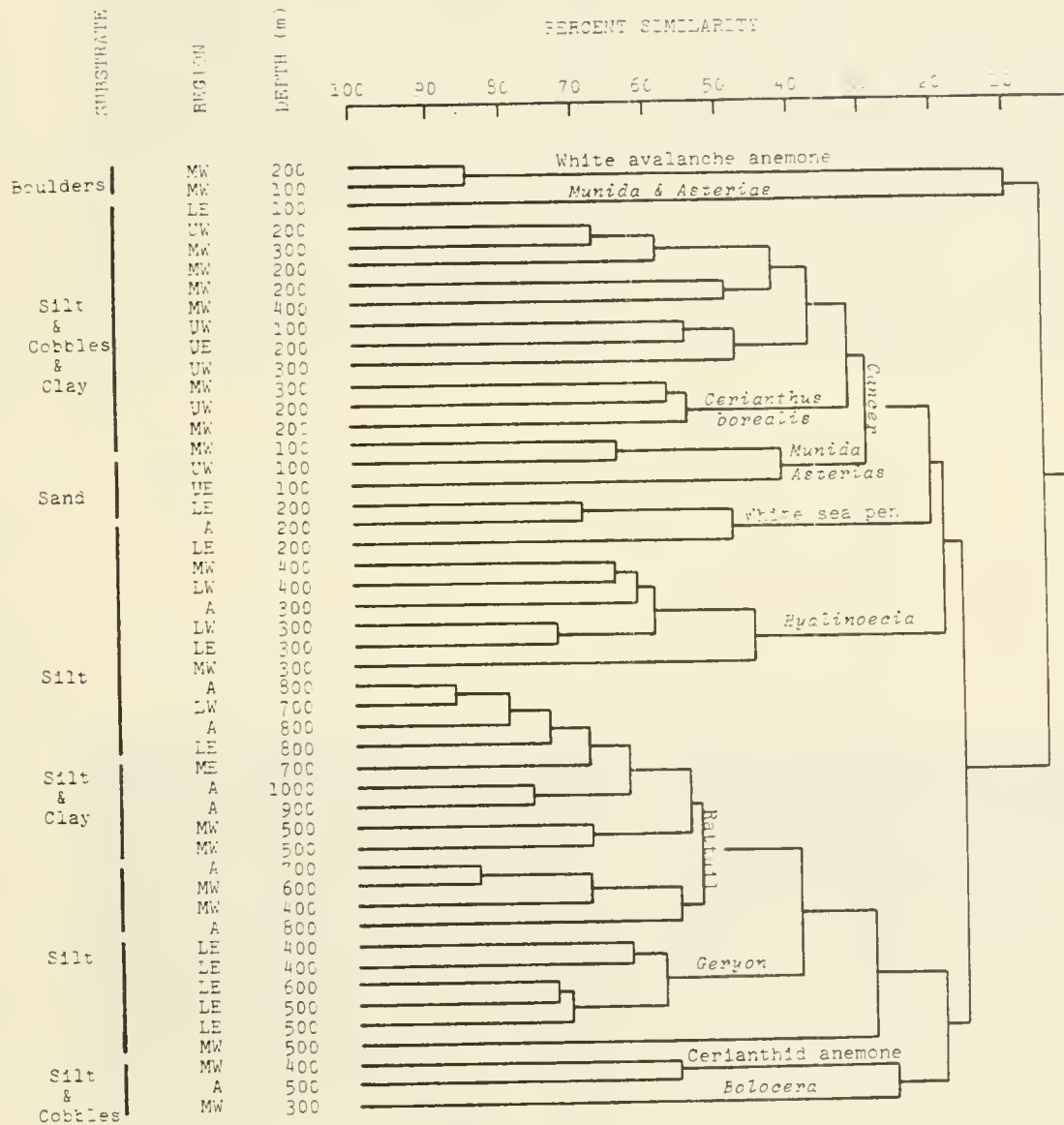
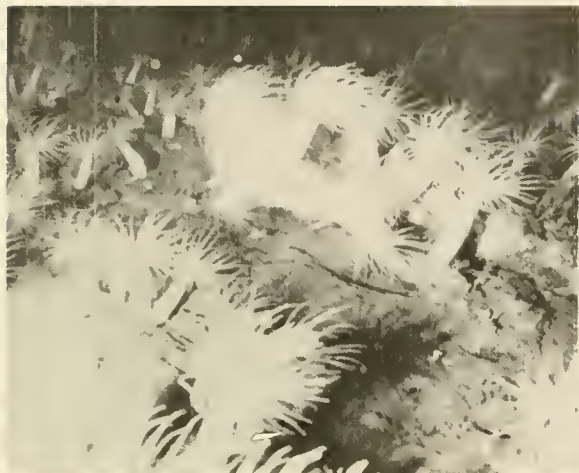
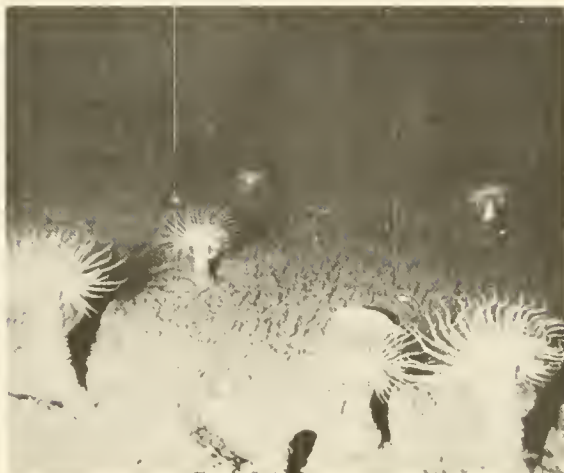


Figure 13. Selected photographs of some of the fauna found in the shallower depths.

- a. A dense concentration of the large white anemone found on boulders in an area on the west wall of Baltimore Canyon (223). The orientation of the tentacles indicates a strong current in this region.
- b. Eight individuals of the burrowing anemone *Cerianthus borealis* and a rosefish at 268 meters in Lydonia Canyon. The anemone in the foreground is retracted into its tube.
- c. Many small anemones encrusting a boulder at 442 meters in Oceanographer Canyon. Also seen is a mating pair of *Cancer borealis* and a galatheid crab.
- d. Several large anemones, *Actinoscyphia saginata* and *Bolocera tuediae*, and numerous quill worms *Hyalinoecia artifex* at 333 meters in Lydonia Canyon. Note two individuals of the jonah crab, *Cancer borealis*, frequently seen at the base of large anemones.



a



b



c



d

107

Figure 14. Map of the principal component end-members
for the areas surveyed in Baltimore Canyon.

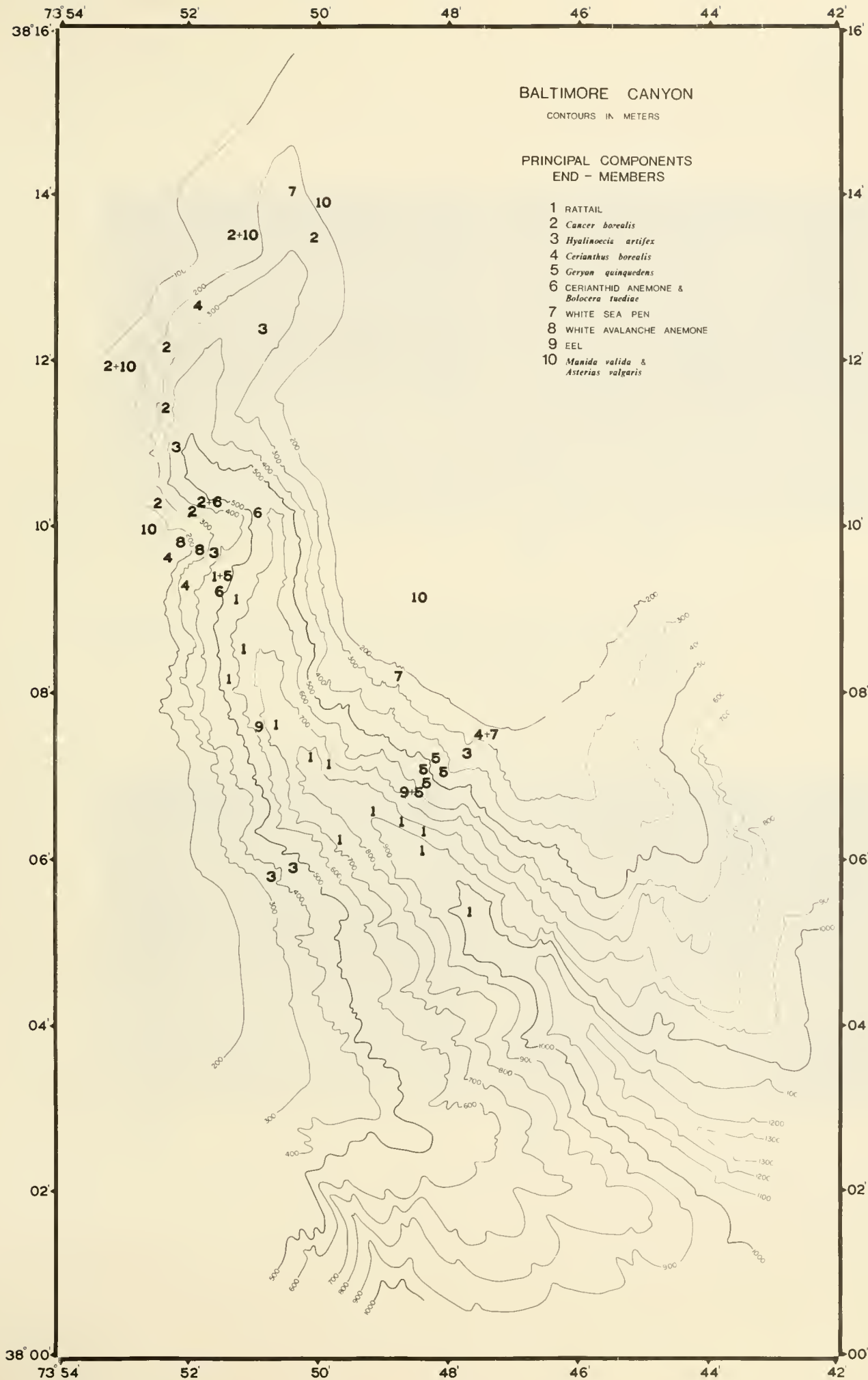
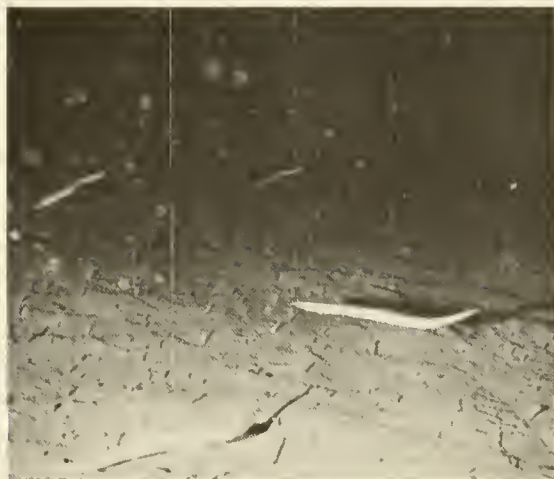


Figure 15. Selected photographs of some middle depth fauna.

- a. The large red crab, *Geryon quinquedens*, seen in a defensive posture at 870m in Oceanographer Canyon. Numerous small barnacles are attached to its carapace and legs.
- b. The deep-sea eel, *Synaphobranch kaupi*, at 1020 meters in Baltimore Canyon. Also seen are numerous polychaete tubes protruding from the sediment.
- c. A large flounder and several individuals of the sponge genus *Cladorhiza* at 870 meters in Lydonia Canyon.
- d. Many shrimp on some boulders and in a large colony of the gorgonian *Primnoa resede* at 563 meters in Lydonia Canyon.



a



b



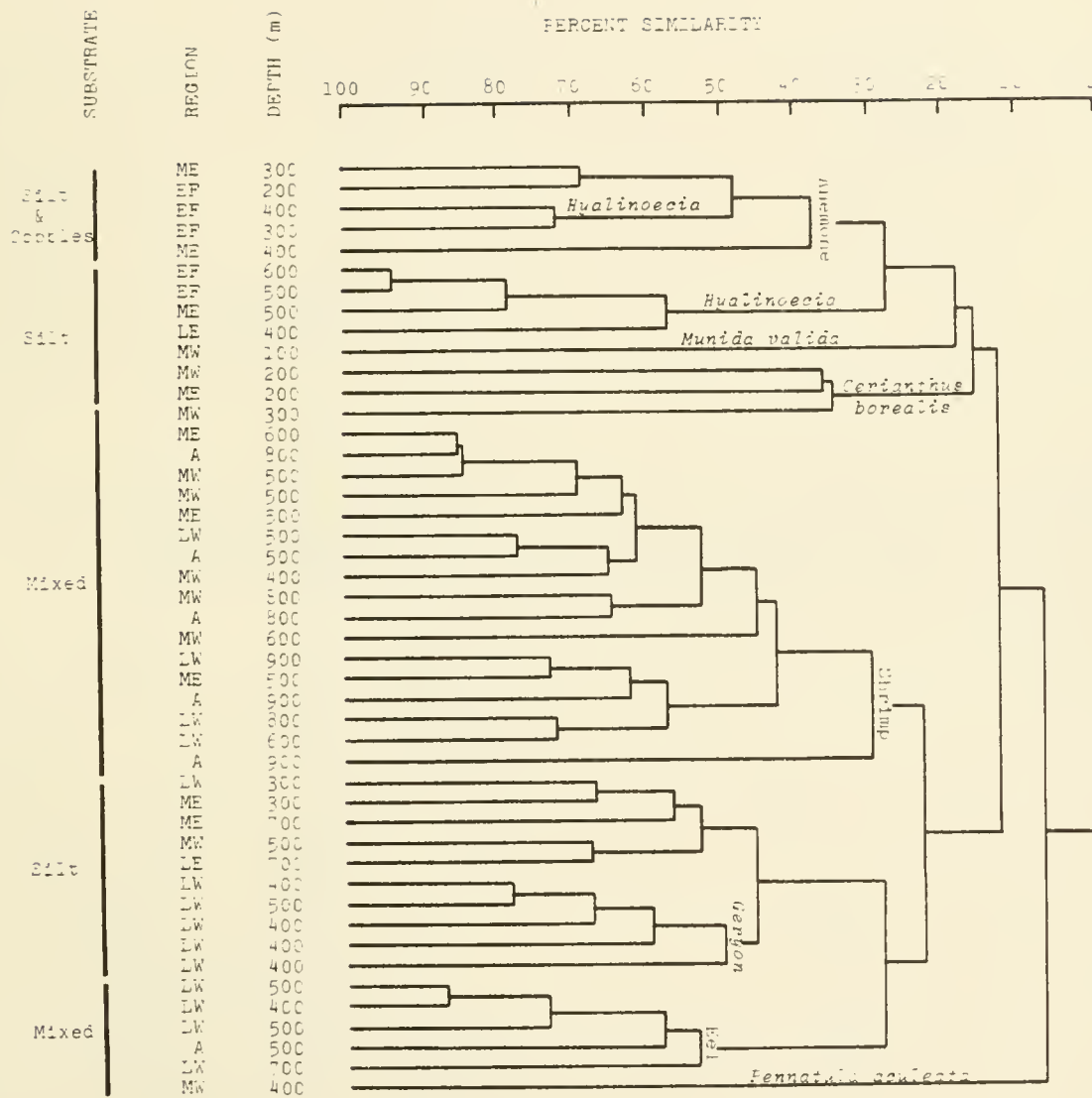
c



d

Figure 16. Cluster diagram of the percent species similarity for various areas in Lydonia Canyon. Species and taxa indentified on the joins represent dominant fauna in those areas.

A = axis
 MW = middle west wall
 LW = lower west wall
 ME = middle east wall
 LE = lower east wall
 EF = east flank

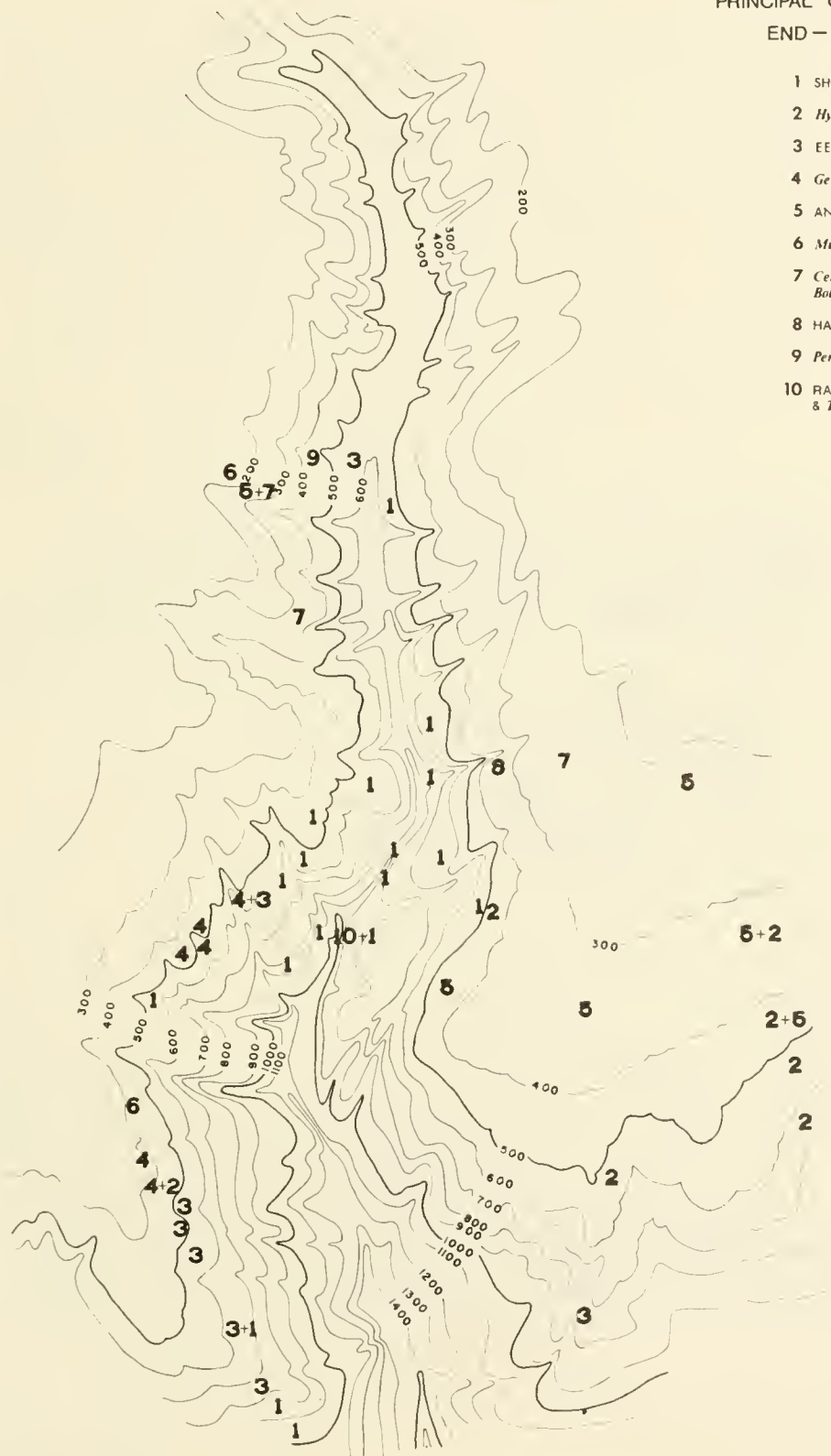


.

Figure 17. Map of the principal component end-members
for the areas surveyed in Lydonia Canyon.

CONTOURS IN METERS

- 1 SHRIMP
- 2 *Hyalinoecia artifex*
- 3 EEL
- 4 *Geryon quinquedens*
- 5 ANEMONE
- 6 *Munida valida*
- 7 *Cerianthus borealis* &
Bolocera tuediae
- 8 HAKE & HERMIT CRAB
- 9 *Pennatulula* sp.
- 10 RATTAIL, SPONGE
& *Trachythela rudis*



40°
17'

Figure 18. Cluster diagram of the percent species similarity for various areas in Oceanographer Canyon. Species and taxa identified on the joins represent dominant fauna in those areas.

A = axis
 UW = upper west wall
 MW = middle west wall
 WF = west flank
 ME = middle east wall
 LE = lower east wall

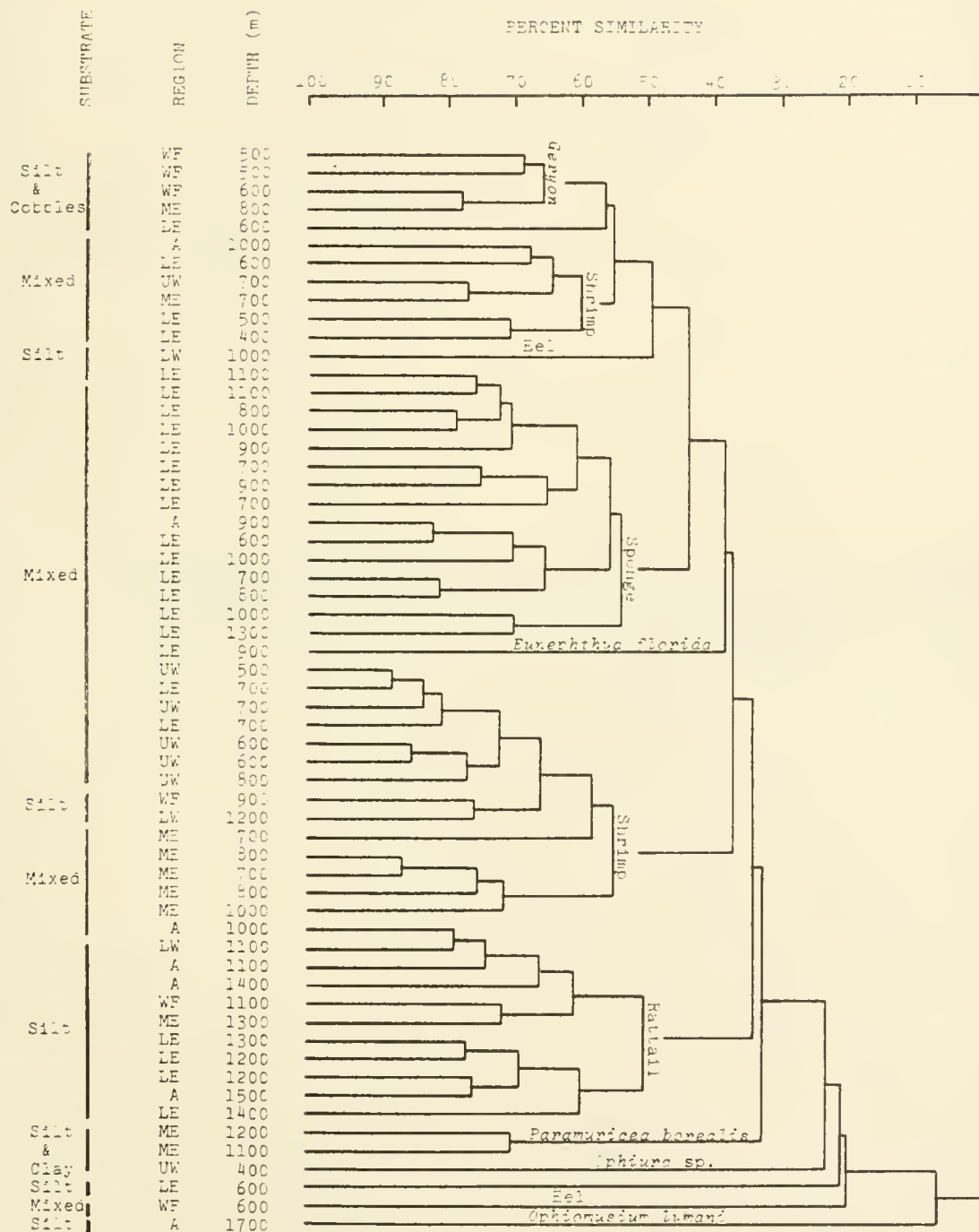


Figure 19. Map of the principal component end-members
for the areas surveyed in Oceanographer
Canyon.

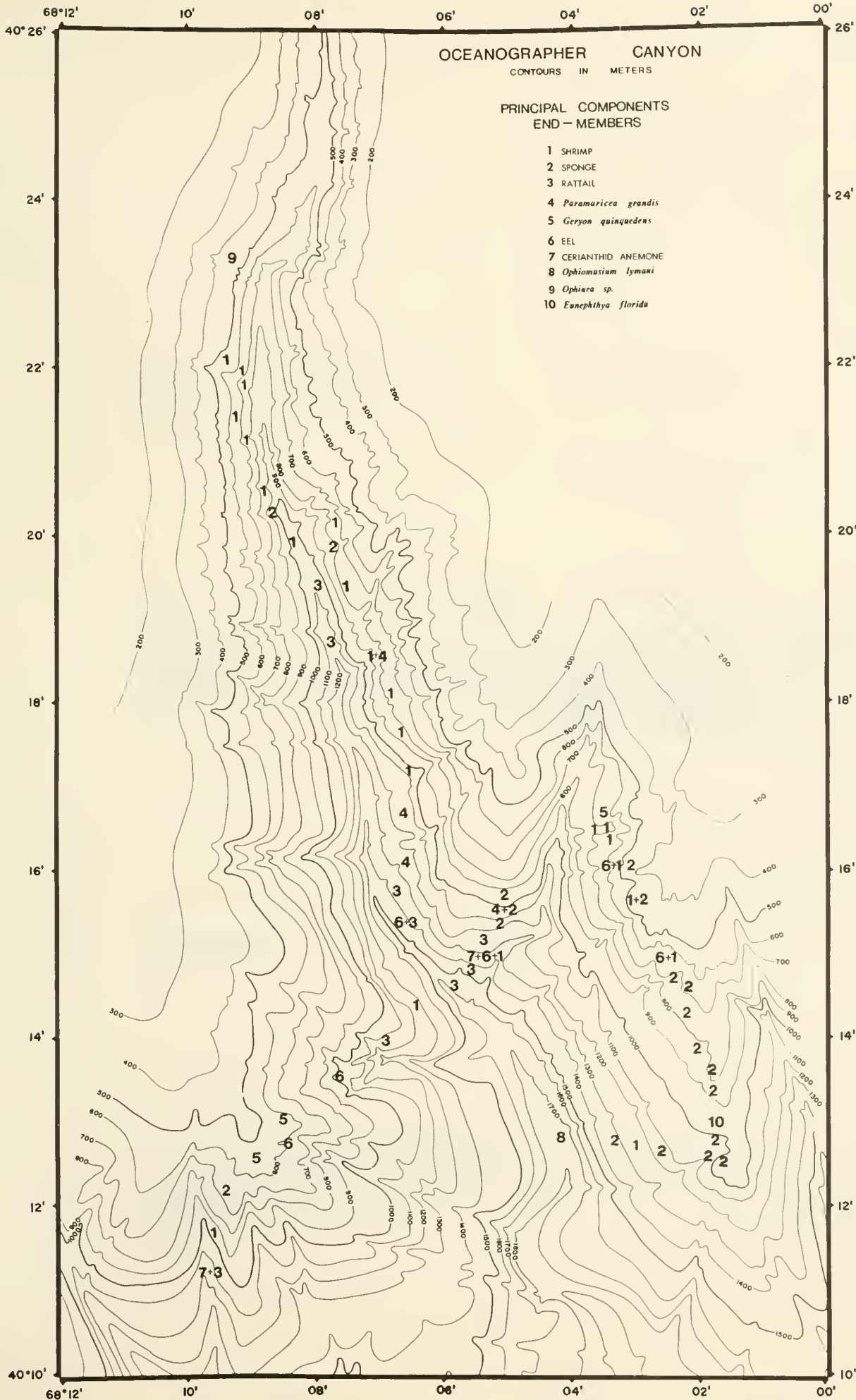
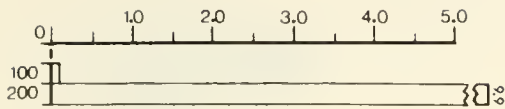
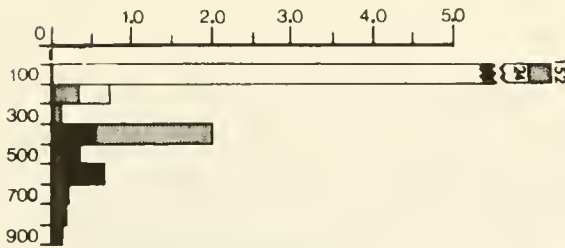


Figure 20. Histograms showing the depth distribution of the dominant shallow water species standardized to individuals per 100m^2 for 100 meter depth intervals.

NUMBER / 100 m²

White sea pen

*Munida valida*

BALTIMORE CANYON
 OCEANOGRAPHER CANYON
 LYDONIA CANYON

DEPTH INTERVAL (m)

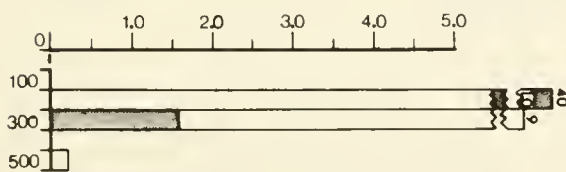
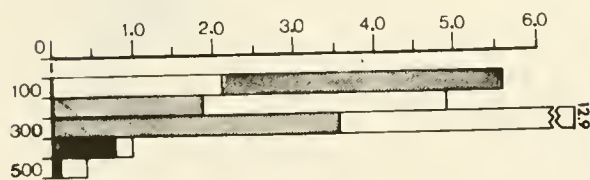
*Cerianthus borealis**Cancer borealis*

Figure 21. Histograms showing the depth distribution of *Cancer borealis* and *Geryon quinquedens* standardized to individuals per 100m² for 100 meter depth intervals.

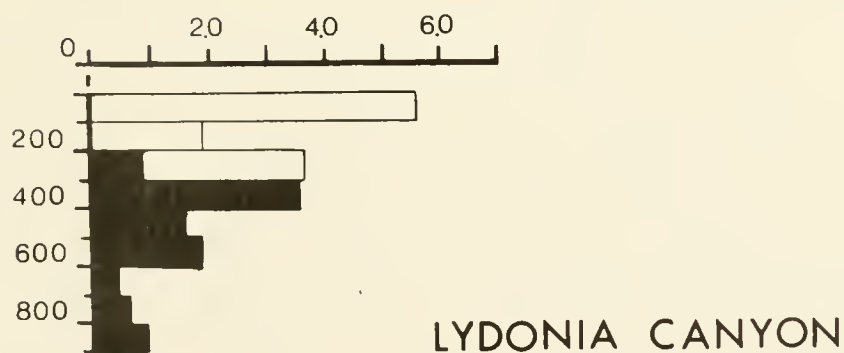
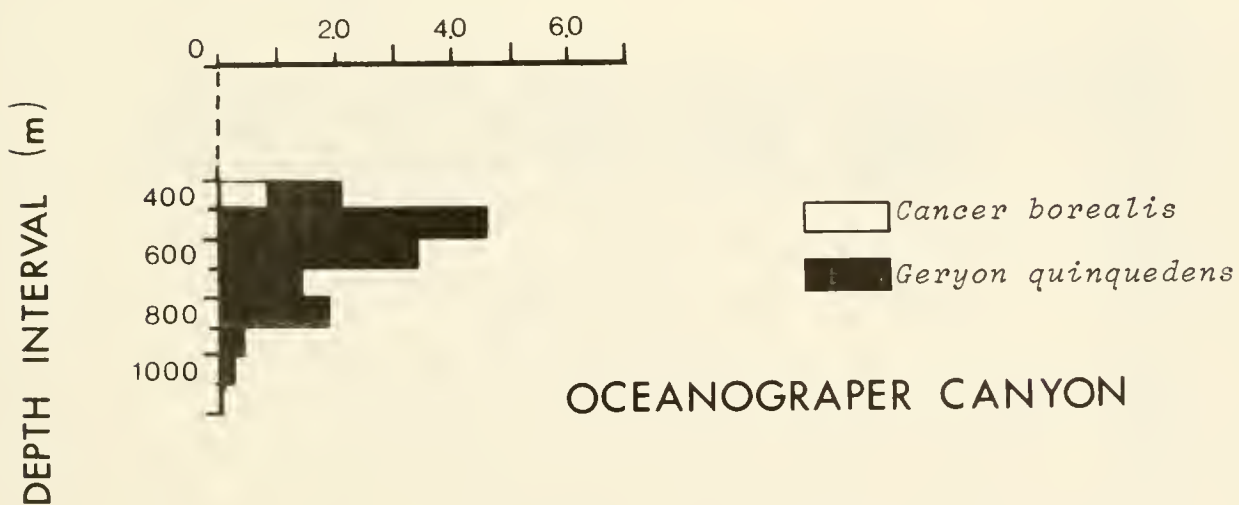
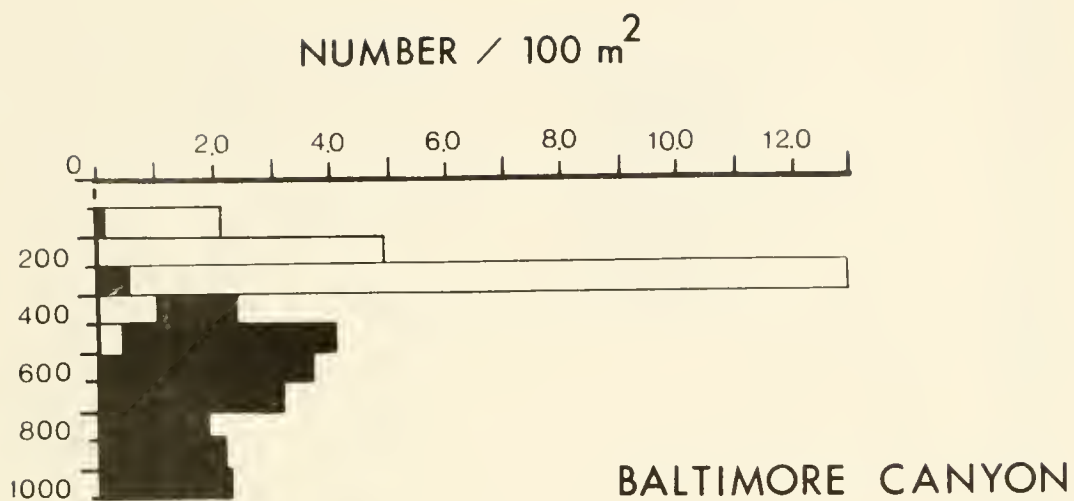


Figure 22. Map of the coral species found in Baltimore Canyon. This includes data from the photographic survey, dredges and submersible dives.

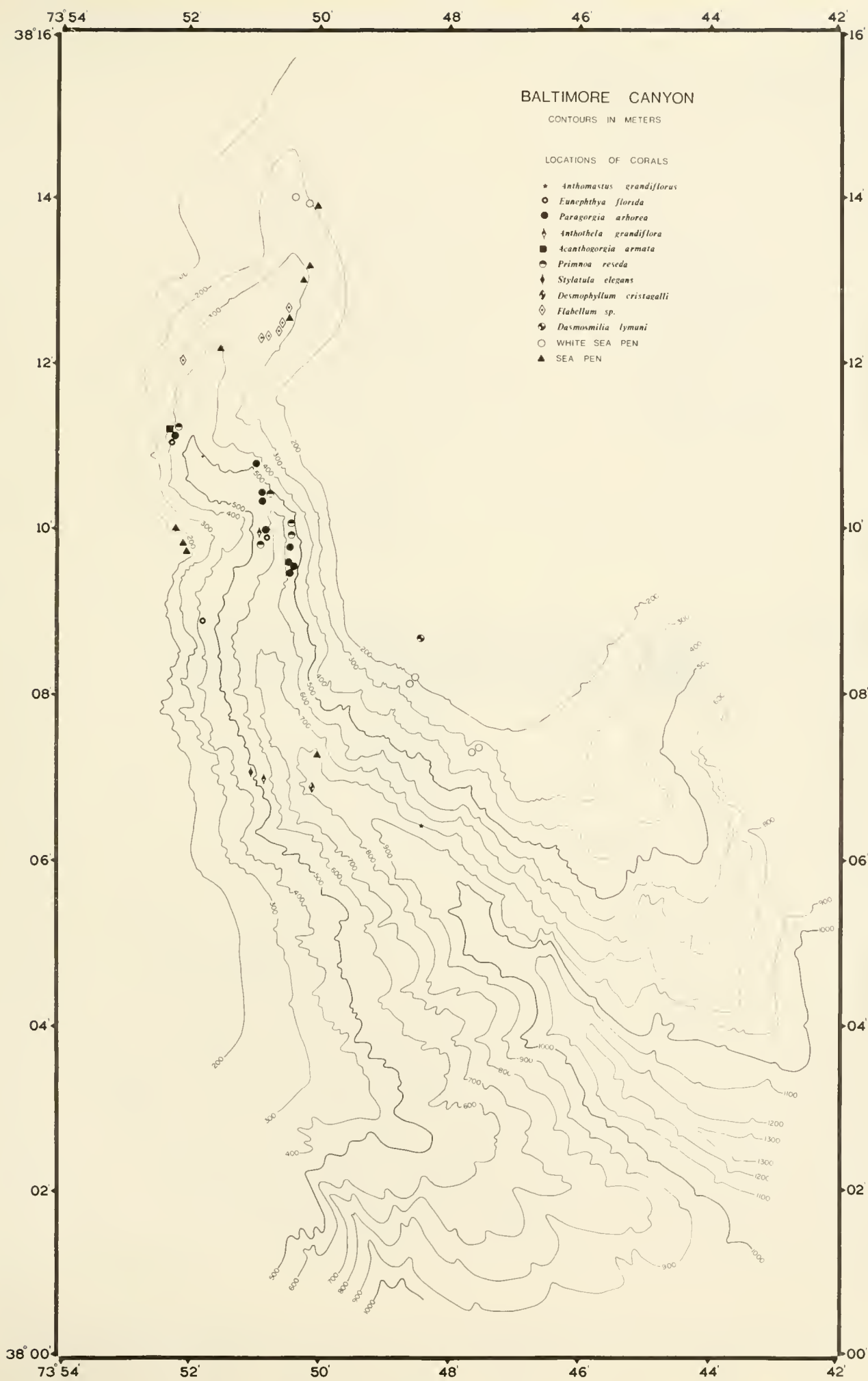


Figure 23. Map of the coral species found in Lydonia Canyon. This includes data from the photographic survey and dredges.

LYDONIA CANYON

CONTOURS IN METERS

LOCATIONS OF CORALS

- *Eunephthya glomerata*
- *Eunephthya flarida*
- ◇ *Trachythelm radis*
- *Paragorgia arborea*
- ◆ *Anthothela grandiflora*
- *Acanthogorgia armata*
- *Paramuricea grandis*
- *Primnoa reseda*
- *Pennatula* sp.
- ⊕ *Kophobelemnon stelliferum*
- ⊖ *Distichoptilum gracili*
- ◆ *Desmophyllum cristagalli*
- ▲ SEA PEN



Figure 24. Map of the coral species found in Oceanographer Canyon. This includes data from the photographic survey, dredges and the historical survey (ALVIN dives 779, 784 and 785).

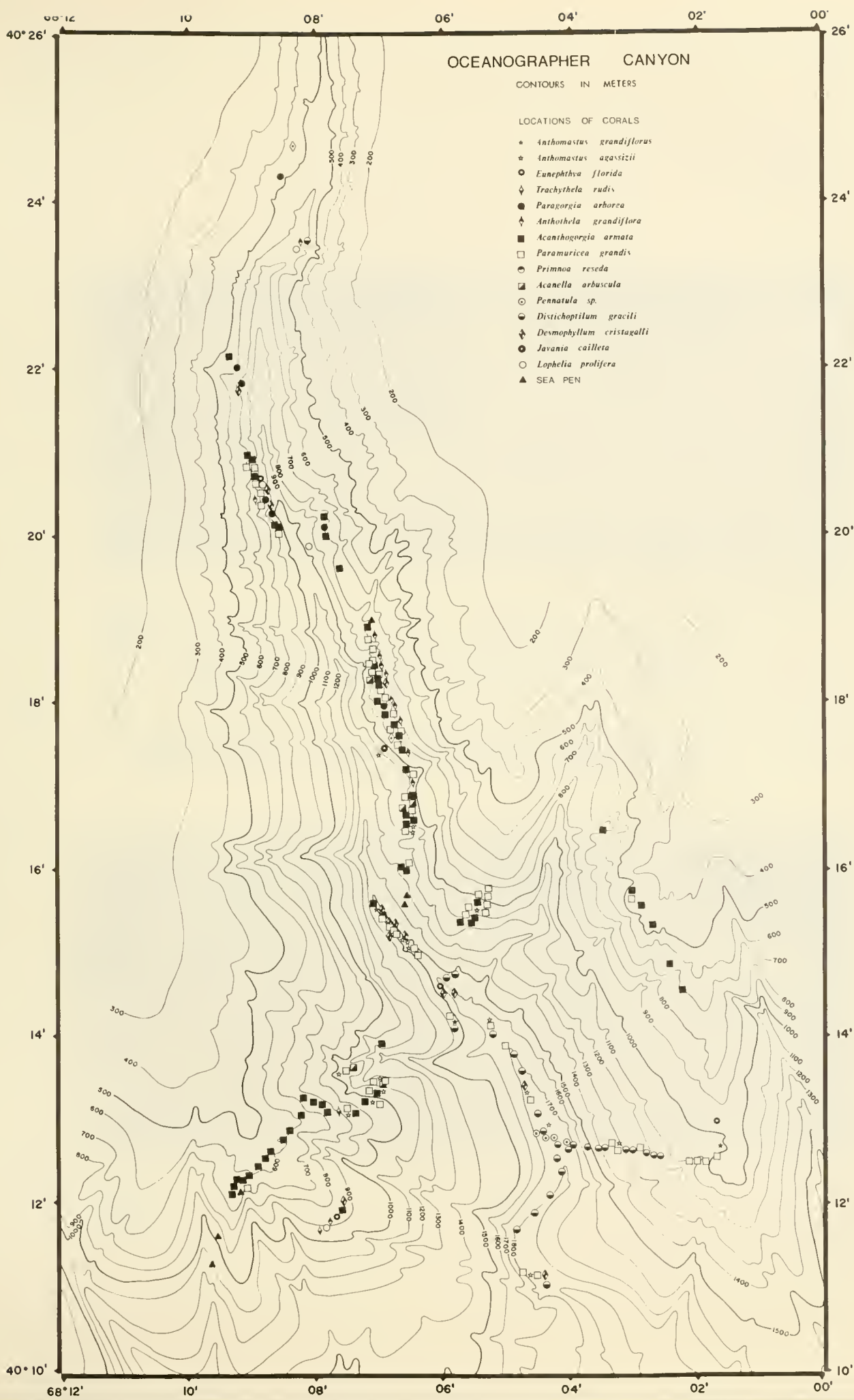
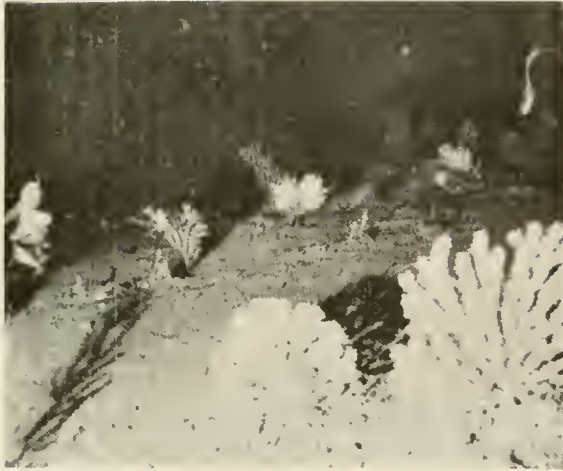
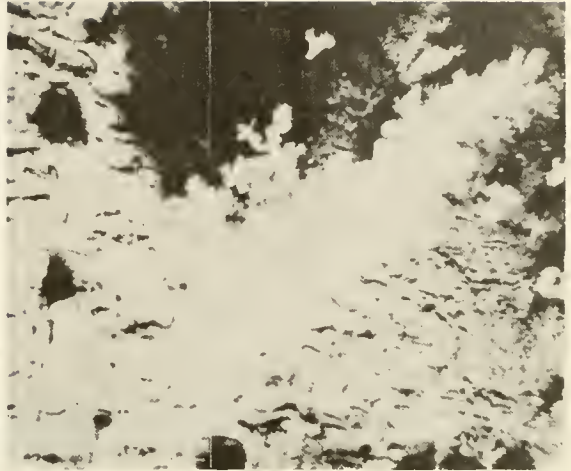


Figure 25. Selected photographs of some of the common corals seen in this survey.

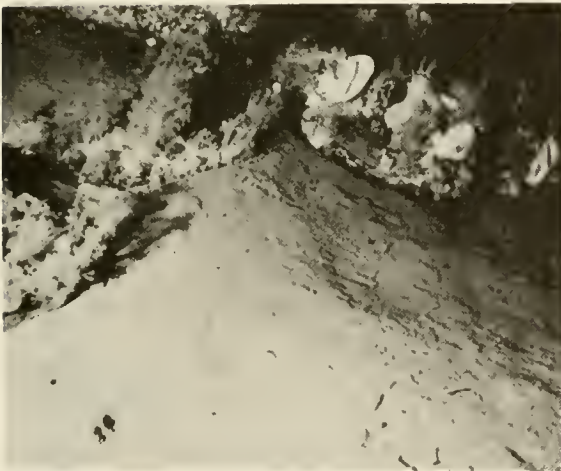
- a. The gorgonian *Paramuricea grandis* and several other soft corals at 865 meters in Oceanographer Canyon. Also seen are several individuals of the sponge *Cladorhiza* and two rattails.
- b. The gorgonian *Acanthogorgia armata* and several *Desmophyllum cristagalli* polyps on an outcrop at approximately 1050 meters in Norfolk Canyon.
- c. Numerous colonies of the alcyonacean *Eunephthya florida* on boulders at 560 meters in Lydonia Canyon. Many sponges and serpulid polychaetes are seen encrusting these boulders.
- d. A medium sized colony of the gorgonian *Paragorgia arborea*, several small colonies of *Primnoa reseda*, and sponges on a boulder at 550 meters in Lydonia Canyon.



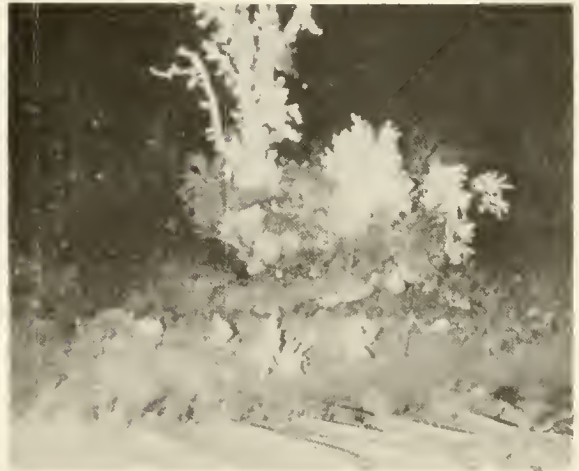
a



b



c



d

Figure 26. Histograms of the abundance and depth of four corals in Oceanographer and Lydonia Canyons, standardized to individuals per 100m² for 100 meter depth intervals.

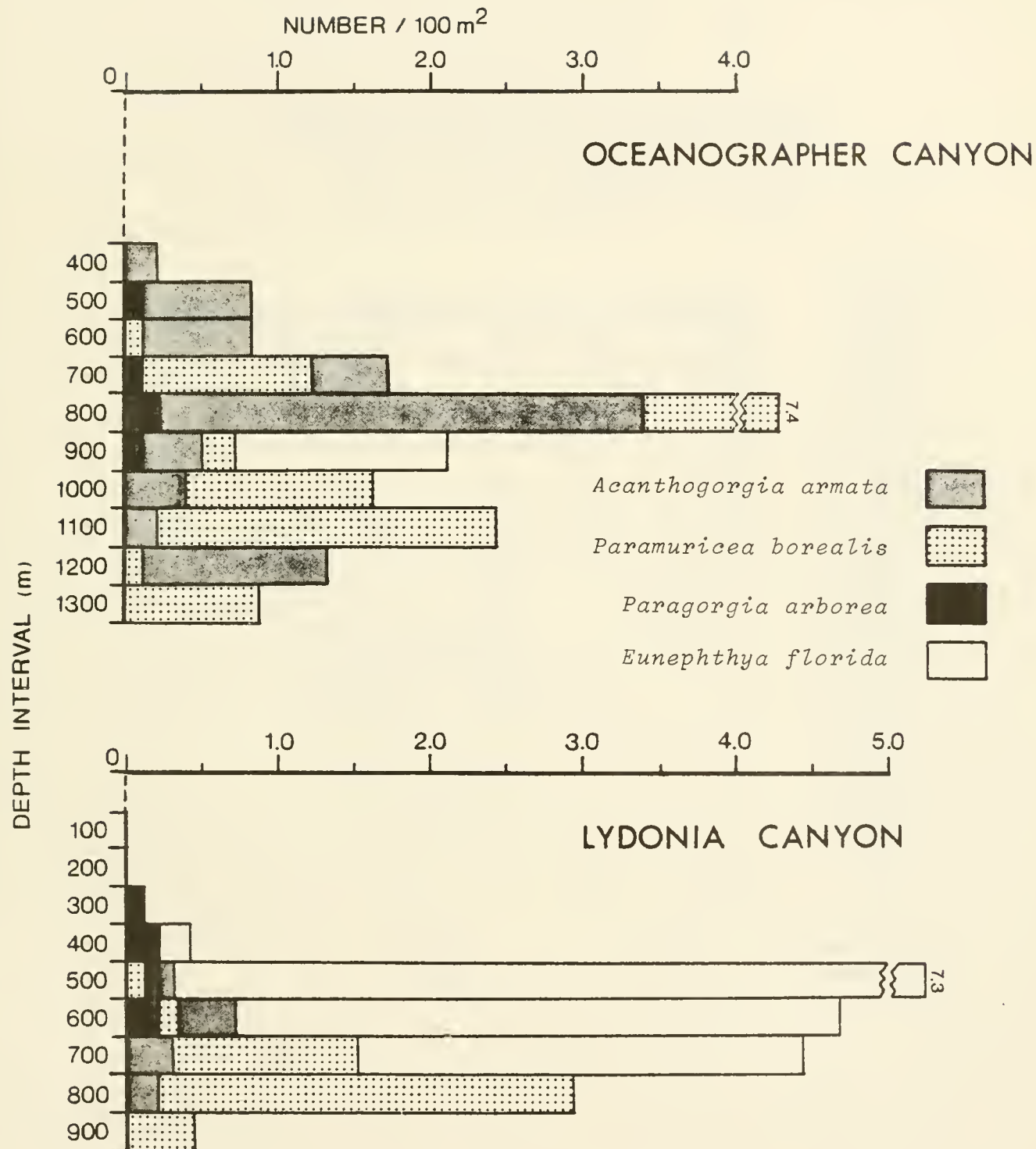


TABLE I: Total area (m²) viewed for 100 meter depth intervals in different parts of the canyons.

DEPTH INTERVAL (m)	BALTIMORE CANYON			OCEANOGRAPHER CANYON			LYDONIA CANYON		
	West Wall	Axis	East Wall	West Wall	Axis	East Wall	West Wall	Axis	East Wall
100-199	1982		1042				160		
200-299	2281	347	785				155		153
300-399	810	1001	813				254		1399
400-499	2589		499	1392		805	1471		574
500-599	577	309	328	1272		181	1398	1143	773
600-699	976		97	1270		528	1108	6	533
700-799	79	894	362	515		1901	158	2	190
800-899		811		115		879	384	216	
900-999		610		135	76	741	115	123	11
1000-1099		368		292	1612				
1100-1199				915	342	1279			
1200-1299				128		737			
1300-1399						872			3
1400-1499				30	116	133			
1500-1599					345	37			
1600-1399				3		10			
1700-1799					214				
TOTAL	9294	4340	3926	6067	2705	9661	5203	1511	3641
TOTAL/CANYON	17,560			18,433			10,355		
GRAND TOTAL				46,348					

TABLE II: First ten end-members of the total fauna for all three canyons and the percent of sample variance explained by them.

<u>Factor</u>	<u>Species</u>	<u>Variance</u>	<u>Cummulative Variance</u>
1	Shrimp	22.53	22.53
2	Rattail	12.00	34.53
3	<i>Hyalinoecia artifex</i>	7.45	41.98
4	Sponge	10.20	52.18
5	<i>Geryon quinquedens</i>	8.68	60.86
6	Eel	9.19	70.05
7	<i>Munida valida</i>	3.20	73.25
8	<i>Cerianthus borealis</i> Anemone	3.66	76.91
9	Cerianthid anemone	3.30	80.21
10	<i>Cancer borealis</i>	4.44	84.65

TABLE III: Results of the rotated principal components analysis for all three canyons. The end-members are listed in order of their dominance within a depth interval, such that the first number is the most common and the last number is the least common. The number in parentheses is the total number of intervals explained by these end-members.

DEPTH INTERVAL (m)	BALTIMORE CANYON			OCEANOGRAPHER CANYON			LYDONIA CANYON		
	<u>West Wall</u>	<u>Axis</u>	<u>East Wall</u>	<u>West Wall</u>	<u>Axis</u>	<u>East Wall</u>	<u>West Wall</u>	<u>Axis</u>	<u>East Wall</u>
100-199	10,7(6)		7,4(3)				7(1)		
200-299	8,10,4,1(7)		10,8(2)				8(1)		8(1)
300-399	3,10,8(6)	3(1)	3(1)				5,8(2)		8,3(4)
400-499	9,2,10,3(4)		5(2)		1(1)		5,6,3,7,1(8)		3,9(3)
500-599	2,6(3)	9(1)	5(2)	1,5,2(5)	1,6(2)		6,1,5(8)	6,1(2)	3,1,2(5)
600-699			6,5(2)	1,4,6(5)	1,5,7,4(5)		1,6(3)		1,3(2)
700-799	2(1)	2(1)	2(1)	1(2)	1,4,2(10)		6,4(2)		2,6,1(3)
800-899		2(3)	2,6(2)	1(1)	4,1(5)		1,6(3)	1(1)	1(1)
900-999		2(1)		1(1)	4(1)	4(2)	1(1)	1(1)	
1000-1099		2,6(2)		6(1)	2,1(2)	4(3)			
1100-1199				9,2,6,1(5)	2(1)	4,1(3)			
1200-1299				1(1)		2,1(2)			
1300-1399						9,6,1,4,2(6)			
1400-1499					6,2(2)	2(1)			
1500-1599					2,6(2)				

TABLE IV: Common species or taxa found in Baltimore Canyon ranked by relative abundance in their respective depth zone.

	DEPTH ZONE			
	SHALLOW		MIDDLE	
	100-299 m		300-1099 m	
	#	%	#	%
White avalanche anemone	1223	(31.3)		
<i>Munida valida</i> (galatheid crab)	764	(19.5)	1	-
White sea pen	340	(8.6)		
<i>Cerianthus borealis</i> (anemone)	336	(8.6)	250	(3.5)
Fish	298	(7.6)	389	(5.5)
<i>Cancer borealis</i> (crab)	232	(6.0)	374	(5.3)
<i>Asterias vulgaris</i> (starfish)	98	(2.5)	3	-
Anemone	75	(1.9)	46	(0.6)
Starfish	63	(1.6)	21	(0.3)
Rosefish	58	(1.5)	22	(0.3)
Sponge	47	(1.2)	25	(0.3)
Flounder	41	(1.0)	52	(0.7)
<i>Hyalinoecia artifex</i>	11	(0.3)	3011	(43.0)
Rattail	12	(0.3)	672	(9.6)
Cerianthid anemone			513	(7.3)
<i>Geryon quinquedens</i> (crab)	2	-	253	(3.6)
Eel	23	(0.6)	238	(3.4)
Gastropod	53	(1.3)	204	(2.9)
<i>Bolocera tuediae</i> (anemone)	15	(0.4)	194	(2.7)
Shrimp	38	(1.0)	178	(2.5)
<i>Actinauge longicornis</i> (anemone)	27	(0.7)	141	(2.0)
Hake	53	(1.3)	133	(1.8)
Hermit crab	37	(0.9)	88	(1.2)

TABLE V: Common species or taxa found in Lydonia Canyon ranked by relative abundance in their respective depth zone.

	DEPTH ZONE			
	SHALLOW 100-299 m		MIDDLE 300-1099 m	
	#	%	#	%
Anemone	464	(41.7)	2451	(23.8)
<i>Munida valida</i> (galatheid crab)	286	(25.7)	24	(0.2)
<i>Cerianthus borealis</i> (anemone)	124	(11.2)	104	(1.0)
<i>Actinauge longicornis</i> (anemone)	96	(8.6)	109	(1.0)
Starfish	26	(2.3)	17	(0.2)
<i>Cancer borealis</i> (crab)	15	(1.2)	62	(0.5)
Hermit crab	13	(1.2)	96	(0.9)
Rosefish	13	(1.2)	24	(0.2)
<i>Hyalinoecia artifex</i> (quill worm)			1885	(18.3)
Shrimp	3	(0.2)	1705	(16.5)
Eel	1	(0.1)	646	(6.2)
<i>Bolocera tuediae</i> (anemone)	13	(1.2)	638	(6.1)
Sponge			487	(4.6)
Fish	42	(3.7)	420	(4.1)
<i>Eunephthya florida</i> (soft coral)			341	(3.3)
<i>Pennatula aculeata</i> (soft coral)			310	(3.0)
<i>Geryon quinquedens</i> (crab)			169	(1.6)
Rattail	2	(0.1)	165	(1.6)
Cerianthid anemone	1	(0.1)	126	(1.2)
Hake	1	(0.1)	125	(1.2)

TABLE VI: Common species or taxa found in Oceanographer Canyon ranked by relative abundance in their respective depth zone.

	DEPTH ZONE			
	MIDDLE		DEEP	
	300-1099 m		1100-1799 m	
	#	%	#	%
Shrimp	1296	(30.1)	54	(4.6)
Sponge	604	(14.0)	67	(5.6)
<i>Ophiura</i> sp. (brittle star)	562	(13.1)		
<i>Synaphobranchus kaupi</i> (eel)	245	(5.7)	49	(4.2)
<i>Geryon quinquedens</i> (crab)	227	(5.3)	1	(0.1)
<i>Acanthogorgia armata</i> (soft coral)	121	(2.8)	16	(1.3)
Anemone	95	(2.2)	7	(0.6)
Hermit crab	66	(1.5)	3	(0.2)
Gastropod	57	(1.3)	5	(0.4)
<i>Porania insignis</i> (starfish)	54	(1.2)		
<i>Hyalinoecia artifex</i> (quill worm)	47	(1.1)		
Starfish	45	(1.0)	2	(0.2)
<i>Munida valida</i> (crab)	40	(0.9)		
Hake	24	(0.5)	3	(0.2)
<i>Eunephthya florida</i> (soft coral)	21	(0.5)		
<i>Cancer borealis</i> (crab)	21	(0.5)		
<i>Ophiomusium lymani</i> (brittle star)			423	(35.9)
Fish	287	(6.7)	101	(8.6)
<i>Paramuricea grandis</i> (soft coral)	166	(3.8)	88	(7.5)
<i>Pennatula aculeata</i> (soft coral)			87	(7.4)
Rattail	164	(3.8)	81	(6.9)
<i>Asteronyx loveni</i> (brittle star)	26	(0.6)	44	(3.7)
<i>Distichoptilum gracile</i> (soft coral)	1	-	35	(2.9)
Cerianthid anemone	16	(0.4)	34	(2.8)
Soft coral	14	(0.3)	11	(0.9)

TABLE VII: Species or taxa restricted to hard substrates ranked by relative abundance in their respective depth zones.

	DEPTH ZONE					
	SHALLOW 100-299 m		MIDDLE 300-1099 m		DEEP 1100-1799 m	
BALTIMORE CANYON	#	%	#	%	#	%
White avalanche anemone	1233	(85.8)				
<i>Bolocera tuediae</i> (anemone)	15	(1.0)	194	(31.2)		
Shrimp	38	(2.6)	178	(28.6)		
<i>Actinauge longicornis</i> (anemone)	27	(1.9)	141	(22.6)		
Anemone	75	(5.2)	46	(7.4)		
<i>Actinoscyphia saginata</i> (anemone)	1	(0.1)	37	(6.0)		
Sponge	47	(3.3)	25	(4.0)		
<i>Eunephthya florida</i> (soft coral)			1	(0.2)		
LYDONIA CANYON						
Anemone	464	(80.3)	2451	(41.1)		
<i>Actinauge longicornis</i> (anemone)	96	(16.6)	109	(1.8)		
<i>Eunephthya glomerata</i> (soft coral)	2	(0.3)	4	-		
Shrimp	3	(0.5)	1705	(28.6)		
<i>Bolocera tuediae</i> (anemone)	13	(2.2)	638	(10.7)		
Sponge			478	(8.0)		
<i>Eunephthya florida</i> (soft coral)			341	(5.7)		
<i>Desmophyllum cristagalli</i> (hard coral)			60	(1.0)		
<i>Actinoscyphia saginata</i> (anemone)			48	(0.8)		
<i>Trachytheia rudis</i> (soft coral)			41	(0.6)		
<i>Paramuricea grandis</i> (soft coral)			32	(0.5)		
<i>Acanthogorgia armata</i> (soft coral)			25	(0.4)		
<i>Paragorgia arborea</i> (soft coral)			15	(0.2)		
<i>Anthothela grandiflora</i> (soft coral)			10	(0.2)		
<i>Primnoa reseda</i> (soft coral)			5	-		
White feather sponge			2	-		
OCEANOGRAPHER CANYON						
Shrimp			1296	(55.1)	54	(22.8)
Anemone			95	(4.0)	7	(3.0)
<i>Eunephthya florida</i> (soft coral)			21	(0.9)		
<i>Actinoscyphia saginata</i> (anemone)			16	(0.7)	1	(0.4)
<i>Anthothela grandiflora</i> (soft coral)			15	(0.6)	1	(0.4)
<i>Paragorgia arborea</i> (soft coral)			8	(0.3)		
<i>Desmophyllum cristagalli</i> (hard coral)			7	(0.3)		
White feather sponge			4	(0.2)		
<i>Paramuricea grandis</i> (soft coral)			166	(7.1)	88	(37.1)
Sponge			604	(25.7)	67	(28.3)
<i>Acanthogorgia armata</i> (soft coral)			121	(5.1)	16	(6.8)
<i>Anthomastus agassizii</i> (soft coral)			1	-	3	(1.3)

APPENDIX A

EPIFAUNA of the NORTHEASTERN U. S.

CONTINENTAL MARGIN

FINAL HISTORICAL CORAL REPORT

for the

CANYON ASSESSMENT STUDY in the MID- and

NORTH ATLANTIC AREAS of the U. S. OUTER

CONTINENTAL SHELF

by:

Barbara Hecker

and

Gretchen Blechschmidt

July 14, 1979

ABSTRACT

The abundance and distribution of the epibenthic and coral fauna of the mid and north Atlantic continental margin was studied by reviewing photographs from submersible dives. Particular emphasis was placed on the canyon areas. The depths covered ranged from 100 meters to 3200 meters. Three general faunal zones were identified. The shelf and shelf-break province had high faunal densities and was dominated by crustaceans and fish. The mid slope region had lower faunal densities and was dominated by fish. The lower slope was characterized by high faunal densities and was dominated by echinoderms. This pattern, though consistent on the slope, was somewhat different in the canyons. Higher faunal densities, particularly of filter feeding corals and sponges, attest to the greater substrate variability and nutrient enrichment of the canyon areas.

Results of community analysis yielded no discernable cohesive assemblages within our study area. Rather the results indicated that the dominant species are independently distributed with their ranges overlapping in some areas and not in others. On the whole, canyon assemblages tended to be more diverse in terms of trophic types. Some species tended to have discrete depth ranges, while others had very broad depth ranges. The fauna exhibited a pattern of gradual species replacement with increasing depth. Also noted was the tendency of some species to emerge with increasing latitude. This observation could be the result of a variety of environmental parameters. Our

ancillary information is not complete enough at this point to elucidate them.

Corals, both alcyonarians and scleractinians were seen throughout the survey. Coral populations tended to be denser and more diverse in canyon habitats. Some species, such as those restricted to hard substrates were found only in canyons while others, namely soft substrate types were found both in the canyons and on the slope. Discrete assemblages of corals were not identified. Here again, their distributions tended to be independent, such that the coral species were not uniformly associated throughout the study area. This finding indicates that the corals are cueing in to slightly different environmental parameters. However, our lack of ancillary information concerning the fine scale environmental variability within the study area makes it impossible to identify these factors.

Measures of species overlap yielded ambiguous results. Patchy distribution and substrate variability tended to obscure meaningful faunal comparisons. In general, the mid-slope depths indicated high faunal similarities between 50 meter depth intervals. This was also true of the deep slope fauna. The shelf and canyon walls yielded slightly different results. Faunal homogeneity on the shelf tended to be uniformly low between depth intervals. Species similarity in the canyons was extremely variable. This again points to the fact that the environmental heterogeneity of canyons provide unique habitats for their faunal constituents.

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INTRODUCTION

The purpose of this report is to determine the density and distribution of the coral and epibenthic fauna of the eastern United States continental margin. This was accomplished by reviewing all available submersible photographs taken within the study area and comparing the results to published literature. Special emphasis was placed on the epibenthic communities found in submarine canyons. Study of canyon habitats is particularly important in assessing the impact of future development of resources on the continental shelf, because canyons have been implicated as conduits for the channeling of materials from the shelf to the deep ocean (Rowe, 1972). Thus, a thorough understanding of canyon habitats and their fauna is potentially important in understanding the farther ranging impact of resource exploitation on the shelf.

The most striking feature of the continental margin of the eastern United States is that it is incised by dozens of submarine canyons. Most of these canyons are rather minor topographic features, but several, such as Hudson Canyon, occupy an extensive geographic area and are deeply incised. These canyons are the result of extensive denudation of Tertiary and early Cretaceous sediments which occurred primarily during the Pleistocene.

The zonation of epifauna on the continental margins is a relatively new field of interest. In a study of the isopod fauna on the continental margin off Cape Hatteras, Menzies, George and Rowe (1973) found three major faunal zones. Their study identified a shelf faunal province extending to a depth of approximately 246 meters, which is slightly below the shelf break. On the upper continental slope (445-940 m) they found a zone of faunal transition between the shelf and abyssal faunal constituents. This zone is known as the archibenthal zone of transition and is characterized by a gradual replacement of fauna along isobaths (Markle and Musich, 1974). The deeper abyssal faunal province includes the lower portion of the continental slope, the rise and the abyss (1000-5315 m). This zone is occupied by fauna with broad depth ranges and may be further subdivided into upper and lower assemblages. Two major faunal boundaries were identified, the upper one just below the shelf break and the lower one in the region between the upper and lower portions of the slope.

In a study of the epifaunal of the continental slope south of Cape Cod, Haedrich, Rowe and Polloni (1975) found three similar faunal zones with the two major boundaries at 300-400 m and 1000-1100 m. The authors correlate these boundaries with changes in substrate type, sedimentation rate and gradient of the slope. The shallow faunal boundary

occurs where the sandy sediment of the shelf is replaced by the silty sediment of the upper slope. The lower faunal boundary occurs near the start of the lower slope which is steeper, has a lower sedimentation rate and offers a greater degree of substrate variability than does the upper slope. However, the authors do point out that while the zones and boundaries are indicative of the fauna as a whole, individual species may have depth ranges that extend into at least two of the zones. They also noted that the shallow and middle faunal assemblages are dominated by various species of fish, while the deeper zone is dominated by echinoderms.

Rowe and Menzies (1969) and Rowe (1971) studied the epibenthic fauna of Hatteras Canyon and the adjacent slope using a combination of trawls and bottom photographs. Rowe found that some of the dominant species of the continental slope are present in reduced abundances, or are altogether absent, in the canyon axis. This phenomena may be the result of habitat differences between the canyons and the adjacent continental slope. The canyons are characterized by a higher variability of substrate types, such as outcrop, and this provides a more heterogeneous environment. Additionally, canyons differ from slope regions in that they may be areas of nutrient enrichment due to the reported funneling characteristics of canyons (Rowe, 1972).

Haedrich, Rowe, and Polloni (1975) conducted their study of epibenthos using trawls. They found that the

epifauna of a small submarine canyon (Alvin Canyon) was not very distinct from that found on the adjacent slope. However, they do concede that several species may be considered canyon indicators. Their conclusions on the similarity between canyon and slope epifauna might not be indicative of larger canyon systems. Alvin Canyon is rather small and, therefore, may not provide as heterogeneous an environment as the more deeply incised canyons. Additionally, trawls do not adequately sample epifauna from regions of high relief and rock outcrops such as are found in the larger canyons. The investigators, however, did find higher population densities in the canyons. This increased abundance again substantiates the role of canyons in funneling nutrient matter.

The distribution of epifauna within canyons is largely determined by the availability of substrate types (Hecker et al., 1978). Thus an assessment of the density and distribution of fauna cannot be divorced from the geology of the region. There is a distinct difference between the canyon habitats found within our study area. The canyons off Georges Bank are currently sites of active erosion (Ryan et al., 1978), while the mid-Atlantic canyons are reported to be largely inactive (B. C. Heezen, unpublished data; Keller and Shepard, 1978). An exception to this trend is Norfolk Canyon which shows evidence of recent active erosion and unusually high current velocities (E. B. Forde, personal communication; Keller and Shepard, 1978).

Corals are an important constituent of the fauna found in canyons. Many of the coral species, though not all of them, are restricted to hard substrates, such as outcrop and glacial erratics. Additionally, they are suspension feeders relying on the higher current activity for their nutrition. Thus, resource development that alters the characteristics of the water column in the vicinity of canyons might be detrimental to the coral communities. These characteristics make corals good "indicator organisms" for assessing potential environmental deterioration.

DATA SET

The data set for this report consists of information collected from previous ALVIN and DIAPHUS dives. This was accomplished by analyzing color slides taken of the seafloor during the dives. Additionally, the data was augmented by reviewing photographs obtained from camera lowerings within the study area. The study area encompassed the region between Cape Hatteras and Georges Bank from a depth of 100 to 3200 meters. All available submersible dives within this region were surveyed for the historical report.

Table I lists the location and depth of the dives viewed that had adequate picture quality and coverage for systematic review and analysis of the slides. Table II lists the location and maximum depth of dives that had very poor

picture quality or photographs that were not available to us, but from which we collected qualitative data regarding the presence or absence of epifaunal species. Table III is a listing of the location and depth of the camera lowerings reviewed. For ease in visualizing the geographic location of this coverage all the dives and camera lowerings are plotted on Figure A1. Most of the dives are concentrated in or closely adjacent to submarine canyons while the camera lowerings are more widely scattered.

A thorough analysis was made of all dives in which picture quality and coverage warranted. The results of this analysis comprise the quantitative data on which this report is based. Unfortunately, the photographs from many of the submersible dives were of poor visual quality, were lost or were not available to us. Whenever possible these dives were then used to obtain qualitative information; particularly data that expanded the known geographic distribution of coral species. Camera lowerings were also utilized to assess the universality of some of the faunal assemblages viewed in the relatively restricted submersible coverage. The archives and sources that were reviewed include: the Smithsonian Institution, Washington, D.C.; Woods Hole Oceanographic Institution; Lamont-Doherty Geological Observatory; the U.S.G.S. (Woods Hole); NOAA (Miami and Rockville, Maryland); and Dr. Richard Slater (University of North Colorado, Greeley, Colorado).

Qualitative information concerning the occurrence of selected taxa was obtained from NMFS (Woods Hole).

Unfortunately there are large data gaps in the submersible coverage. Most of the usable photographic transects were restricted to the submarine canyons. This allows little opportunity for strict comparison between canyon and slope fauna at equivalent depths. Another problem is that the footage from many of the earlier ALVIN dives is lost or footage was not even taken. Additionally, there is virtually no available photographic record between the depths of 400 to 800 meters and coverage at depths greater than 2000 meters is very sparse.

The photographic method for estimating abundance and distribution of epibenthos has various advantages over trawling or motion pictures. Both of these other methods tend to underestimate epifaunal density, while direct visual observation tends to overestimate it (Grassle et al., 1975). Barham, Ayer and Boyce (1967) compared measures of epifaunal density obtained by still photographs and 16 mm cinemaphotography along a transect in the San Diego Trough. The densities obtained from examination of the still photographs were nearly twice as high as those obtained from a study of the motion pictures. The investigators attributed this difference to the more critical examination possible with camera stills. A comparison of densities estimated from trawls versus still photographs shows that photographs

yield densities in order of magnitude greater than those obtained from trawls (Haedrich, Rowe and Polloni, 1975). This is probably due to the fact that the more mobile components of the epifauna can readily avoid the net. Additionally, the uncertainty of the actual configuration of the net with respect to the bottom is a problem that excludes trawling as a valid quantitative sampling technique.

The main disadvantage of using submersible photographs to determine abundance of epibenthic organisms is that the fixed camera is at a low angle with respect to the bottom. This allows the camera to cover a large area, but also results in amplification of errors in estimates of the area observed. Thus, any deviation of elevation above the bottom can substantially alter the size of the field of view. In such instances estimates of the area viewed can be made in relation to the size of organisms and various topographic features.

METHODS

Slide Examination and Species Recognition

The photographs reviewed from the ALVIN consisted mainly of color slides taken with an externally mounted camera. These were augmented by transcripts of the observers' comments whenever they were available. To calculate abundances of the

faunal constituents estimates of the number of square meters viewed were made. The method that was used is described in Grassle et al., (1975) and employs the use of a Canadian (perspective) Grid. Construction of the perspective grid requires knowledge of the elevation of the camera, the angle of the optical axis of the lens with respect to the image, and the focal length and acceptance angles of the lens in water. These parameters were then used to calculate the number of square meters of the bottom viewed on each slide. Prior to January, 1976 the ALVIN external camera was an EG&G camera which covered a viewable area of approximately 6 m² per frame. ALVIN now uses a Benthos 35 mm camera which covers a viewable area of approximately 9 m². The foreground of the field which is obstructed by the sample basket, and the edges of the frame which are rather dark were not used. For the DIAPHUS dives estimates of approximately 3 m² viewed per slide were used (based on actual measurements).

Each slide was projected on a scaled up replica of the calculated grid and examined. The depth, area viewed, substrate, and species and their abundance was noted for each slide. This data compilation was aided by use of the data sheets given in Appendix 1. Species identification from photographs is extremely tentative. It is virtually impossible to positively identify all the fauna seen in the photographs to the species level. At present, the state of the art of taxonomy of much of the fauna found below the

photic zone is sketchy at best. This is compounded by the fact that the characteristics separating closely related species are frequently too fine to be discernable on a photograph. Additionally, the problem of species recognition is further hampered in many coelenterates, because as a result of contraction dried or fixed specimens frequently look very different in life. Within these constraints every effort was made to make as precise an identification as possible. Identification was aided by compiling information on the distribution and known depth ranges of the various species found within the study area. The compilation of this information was greatly aided by R. Haedrich and G. T. Rowe making their data on trawl collections available. Additionally, consultation with P. Polloni (W.H.O.I.) and various specialists in invertebrate taxonomy, particularly, F. Bayer, S. Cairns, M. Downey and D. Pawson, was very helpful. Hand held photographs taken by observers during dives were also very useful, because they frequently afforded good closeups of some of the major faunal constituents.

A major disadvantage of using submersible photographs to assess epibenthic faunal abundances is that biases may be created by the mere presence of the vehicle and its lights. For instance it has been noted that some fish are attracted to the disturbance created by the submersible, possibly to feed on the infauna exposed by the vehicles displacement of

sediment. Study of photographs would then tend to overestimate the abundance of these species. This was compensated for by not counting individuals that were seen in successive frames. Other organisms, such as the large crab *Geryon quinquidens* and various fish, obviously try to avoid the path of the submersible. Nothing could be done to alleviate this bias, because it is impossible to determine what organism has caused a dust cloud seen in a photograph. Another bias which could not be compensated for is that the habitat of some organisms, such as burrowers or ones that hide beneath rocks, precludes an accurate assessment of their abundances because they are rarely out on the substrate and thus are not seen on the photographs.

Statistical Techniques

The species, their abundance and the m^2 viewed were summed for 50 meter depth intervals for each dive. This data was then standardized by calculating the number of individuals per $100 m^2$, for each species and for the total fauna. The relative percent that each species contributed to the total fauna seen was also calculated for each depth interval. Percentage faunal similarity was calculated between 50 meter depth intervals within a dive and for similar depth intervals between dives. The index used was percentage similarity (Whittaker and Fairbanks, 1958) given by the formula

$$PS = 100(1.0 - 0.5 \sum |p_{ia} - p_{ib}|) = 100 \sum \min(p_{ia}, p_{ib})$$

where p_{ia} is the proportion of sample "a" composed by species "i" and p_{ib} is the same for sample "b". These values were then used to assess faunal similarities between depths and various locations. This method basically measures the degree of faunal overlap, in terms of species composition, between various samples.

To identify patterns of community similarity and species distribution we subjected the data to rotated principal components analysis. Each dive was divided into 50-meter depth intervals. All species seen, and their abundance, within that depth interval were then combined into a composite sample. After elimination of 50-meter depth intervals in which fewer than 50 m² were viewed, we retained 169 composite samples. Of 133 recognizable taxa possibly occurring in our study area, 30 were not encountered. This resulted in a data matrix of 169 samples and 103 taxa. To facilitate computation, while still analyzing all 169 samples at the same time, we needed to reduce the number of taxa to 60. The 43 species that were dropped were taxa that were represented by fewer than 23 individuals in the entire data set. This should not substantially alter the results of the analysis, because generally each sample was dominated by only a few species.

Distributional patterns of faunal assemblages were studied by analyzing the degree of species similarity between samples. This type of community analysis is usually referred to as Q-mode analysis (Poole, 1974). For this type of analysis the sample compositions are normalized to a standard unit length, so that the sum of squares of the species abundances within each sample is one. As a result each sample contributes equally to the analysis. It should be noted that this normalization of the data does not change the proportional contribution of the species to the sample composition.

The cosine-theta statistic was used as a measure of sample similarity. This measure can be visualized as the cosine of the angle between sample vectors, where the vectors are a geometrical representation of the samples' species composition in a hyperspace having dimensions equal to the number of species. The cosine-theta statistic is computed by postmultiplying the now-normalized data matrix by its transpose. This statistic ranges from zero when samples are very dissimilar (forming a large angle) to unity when the samples are identical (forming a small angle). The cosine-theta matrix was then analyzed for its eigenvalues (amounts of the sample variance accounted for by successive axes) and eigenvectors (composite-species axes defining faunal assemblages). The method allows for the fewest possible assemblages describing the maximum amount of the data, by

constructing new component species axes so that each successive axis accounts for the greatest fraction of the remaining total sample variance.

These new principal component axes were rotated to a "best fit" position, defined by the Varimax criterion (Klovan and Imbrie, 1971). The principal components represent mathematically independent end-member samples (species or groups of species), with each real sample being described to a lesser or greater degree by an appropriate mixture of these end-members. Rotation of the components to a "best-fit" position introduces no distortion or loss of information. The value of this technique is that the composition of the mathematically independent end-members tends to be close to real, and therefore more readily interpretable, samples. Each sample was then classified in terms of its faunal composition with respect to the identifiable end-member assemblages.

RESULTS AND DISCUSSION

Substrates

A variety of different substrates and habitats were found within the study area. On the whole, canyons offer a more heterogeneous environment in terms of substrate variability than does the slope. Silty sediment is the major substrate found within this area, both in canyons and on

the slope. Sandy sediment is generally confined to the shelf, the upper slope and canyon heads. It is also intermittently found on canyon walls and in their axes. Consolidated clay outcrop is found in canyons and on the lower continental slope. Loose hard substrates, such as cobbles and glacial erratics, are primarily found in the heads and on the walls of the northern canyons. Rock outcrops are usually restricted to canyon axes, with occasional outcrops on the canyon walls.

The continental shelf and upper slope (100-350 m) of the mid-Atlantic region is characterized by a sandy substrate with shell fragments and coral debris. From 350 to 500 meters depth the substrate is silty with occasional cobble patches and boulders. The lower continental slope (850-2550) of the mid-Atlantic region consists mainly of silty substrate with occasional minor consolidated clay outcrops below 1000 meters.

Data was obtained for the depth intervals of 1050 to 1600 meters and 2150 to 2350 meters in the axis of Norfolk Canyon. The predominant substrate is a silty sediment. Substantial outcrops were seen in the depth interval from 1050 to 1500 meters, while only occasional outcrop was seen deeper. The head of Carteret Canyon is characterized by predominantly sandy sediment with occasional shell fragments on its north flank (150-350 m). Outcrop of consolidated Pleistocene clay is found at a depth of 250 meters on the

south flank of the canyon head. The head of Toms Canyon has sandy sediment with shell fragments throughout the 150 to 350-meter depth range. Hudson Canyon consists mainly of a silty sediment, with minor consolidated clay outcrops throughout its axis. In the deeper part of Hudson Canyon (2900-3000 m) substantial outcrops were seen.

The continental slope between Hudson Canyon and Georges Bank is characterized by silty substrate between 1250 and 1400 meters. From 1700 to 2250 meters the sediment is also silty, with minor consolidated clay outcrops throughout this depth interval.

The head of Veatch Canyon consists of sandy sediment between the depths of 100 to 250 meters. Major consolidated clay outcrops were seen between 150 and 200 meters in this canyon. The head of Lydonia Canyon (150-400 m) offers a slightly more heterogeneous habitat. It has a predominantly sandy substrate interspersed with gravel, cobbles and glacial erratics. Large ripple marks were also observed indicating strong current activity.

The northern canyons offer the most heterogeneous environment in terms of substrate variability. The wall of Oceanographer Canyon consists of silty sediment with some sandy areas between 900 and 1200 meters. Consolidated clay, cobbles, glacial erratics and extensive coral rubble were found between 700 and 1350 meters, while outcrop was seen at 1050 and 1400 meters. The axis of Oceanographer Canyon

consists of a silty sediment with occasional sandy patches. The axis is flanked by extensive outcrops on both sides with frequent talus blocks at the base of these outcrops. The wall of Heezen Canyon, a very narrow and deeply incised canyon, consists of silty sediment with minor consolidated clay outcrops between 800 and 1300 meters. The axis of this canyon is extremely narrow and has a silty floor heavily littered with large talus blocks. The axis is flanked by massive outcrops with numerous sediment dusted ledges. The wall of Corsair Canyon is characterized by silty sediment with minor outcrops at 900, 1150 and 1300 meters.

Faunal Density

The density of epibenthic fauna shows a marked variation with depth. Faunal density is uniformly high in the shallower region, with a peak between 350 and 500 meters (Figure B1). The density then drops and remains relatively uniform from 600 to 1600 meters. There is a secondary peak between 1600 and 2300 meters, after which it shows a marked decline to 3150 meters. The shelf and shelf-break regions are areas of high nutrient flux and the fauna is composed of a variety of trophic types. The peak in faunal density between 350 and 500 meters is mostly the result of high concentrations of the scavenging quill worm *Hyalinoecia artifex*. This species has a very patchy distribution and occurs in high concentrations when it is present. Thus,

this peak may be artificially inflated and not indicative of the true density at that depth. The coverage is not complete enough to determine if this is the case. The slope fauna is dominated by fish which are mostly predators and scavengers, while below 1600 meters most of the animals are smaller deposit feeders.

This pattern is somewhat less apparent in canyons. Faunal densities were calculated separately for slope and canyon habitats and the results are shown in Figure B2. Faunal densities within canyons are consistently higher than densities at corresponding depths on the slope. In fact, they do not show the marked decrease in faunal density between the depth of 600 and 1600 meters. However, they do show the peak below 1600 meters which decreases at depths greater than 2300 meters. The higher faunal density in the middle depth range may be explained by the more varied habitats found within canyons when compared to the slope. The canyons offer a variety of substrates and are thought to be conduits for nutrients, they would thus be able to support a greater variety and abundance of organisms.

Faunal Components

The major faunal components seen during the survey were fish, crustaceans, echinoderms and corals. Distinct variations in the relative abundance of these components were noted and several patterns are discernible. Figure C1 is a

diagrammatic representation of the numerical percentage of the fauna accounted for by these groups. The most obvious pattern is the increasing dominance of echinoderms with depth. The shallow fauna is generally composed of crustaceans, fish and a variety of other taxa. The middle depth fauna is dominated by fish, while echinoderms are the major component of the deeper fauna.

These results are consistent with the findings of Haedrich, Rowe and Polloni (1975) and Grassle et al., (1975). The higher nutrients of the shelf and upper slope allow this region to support a greater variety of trophic types. Fish and crustaceans are large mobile predators and scavengers, while some of the other shelf fauna are filter feeders. The deeper slope environment has a lower sedimentation rate and is characterized by a predominance of deposit feeding echinoderms.

The trend of replacement of faunal constituents with depth is best seen in slope areas, such as is shown in Figure C2 for the slope south of Baltimore Canyon. The relative proportion of the major taxa are presented for 50-meter depth intervals. ALVIN dive 765 covered depths ranging from 200 to 450 meters. Crustaceans, such as a species of *Munida* and *Cancer borealis*, dominated the fauna from 200 to 300 meters. The quill worm *Hyalinoecia artifex* was the dominant species seen between 300 to 450 meters. This species appears to have a rather patchy distribution and is found in exceedingly high

abundances (300-400 individuals/100 m²) where it occurs. ALVIN dive 767 covered a depth range of 850 to 1250 meters in the same area. At all depths within this range fish comprise the majority of the epifauna seen. The most abundant of these was the deep-sea eel *Synaphobranchus kaupi* frequently seen hovering just above the bottom. The main crustacean in this region was the deep-sea red crab *Geryon quinquedens* with most of them seen as mating pairs. ALVIN dive 766 covered the depth range from 1550 to 1800 meters. Throughout this dive the predominant animal was the ophiurid *Ophiomusium lymani*.

Figure C3 shows the dominant faunal constituents seen on ALVIN dive 807 covering the depth range from 1000 to 1350 meters on the slope north of Norfolk Canyon. Again fish accounted for the majority of the fauna seen. The dominant crustacean found between 1000 to 1050 meters was *Geryon quinquedens* which burrowed extensively in the consolidated clay bottom as evidenced by numerous large excavations. A species of the solitary cup coral *Flabellum* was seen in high concentrations in the 1300 to 1350-meter depth interval.

The general trend of gradual replacement of crustaceans and fish by echinoderms with increasing depth is somewhat obscured in canyons. This is probably the result of greater environmental heterogeneity in canyons due to more substrate variability. Additionally, canyons have been identified as nutrient enriched environments (Rowe, 1971; Haedrich, Rowe

and Polloni, 1975). The environmental heterogeneity and increased nutrient flux would allow canyons to support a greater variety of species and trophic types. As a result, canyons tended to have higher concentrations of corals. A notable exception to this was Hudson Canyon which was pre-dominated by fish and crustaceans, and followed the more general trend seen on the slope. This may well be due to the scarcity of outcrop within its axis.

Norfolk Canyon is the only mid-Atlantic canyon in which there is deeper dive coverage. Figure C4 shows the major faunal components seen during dive transects in the axis of this canyon. Dive 808 covered the depth range from 1050 to 1250 meters. All depths within this dive were dominated by the quill worm *Hyalinoecia artifex*. The corals which comprised a minor component of the fauna were the solitary horn coral *Desmophyllum cristagalli* and a white gorgonian *Acanthogorgia armata*, both of which require a hard substrate. Dive 809 covered the axis from 1200 to 1550 meters. A variety of trophic types were found in this interval. *Geryon quinquedens* dominated the first 50-meter depth interval. A species of the burrowing cerianthid anemone dominated from 1250 to 1450 meters, fish dominated from 1500 to 1550 meters, while two soft corals *Anthomastus grandiflorus* and a species of *Pennatula* dominated the last interval. During dive 810 deeper in the canyon axis the same two soft corals, *A. grandiflorus* and *Pennatula* sp., dominated between 2150 and 2350 meters.

The trend is also obscured in the northern canyons. Figure C5 shows the results of faunal observations made from three ALVIN dives in Oceanographer Canyon. One dive covered the west wall between 650 to 1550 meters while the other two dives covered the canyon axis between 1450 and 1900 meters. The canyon wall consists of a variety of different substrates and no single taxa or trophic type predominates. *Geryon quinquedens* is common in the shallower part as well as several species of large starfish. Two gorgonians *Acanthogorgia armata* and *Paramuricea borealis*, and an octocoral *Anthomastus agassizii*, which are restricted to hard substrates, are also common in this area. One very unique feature of this region is the presence of extensive coral rubble formed by dead and broken pieces of the colonial scleractinian *Lophelia prolifera*. This rubble provides a very heterogeneous substrate for a variety of attached taxa. Below 1150 meters fish and shrimp dominate the fauna. The fauna in the axis of Oceanographer Canyon is dominated by *Hyalinoecia artifex* and fish from 1450 to 1550 meters, while between 1550 to 1600 meters it is dominated by *Desmophyllum cristagalli*, a solitary coral restricted to hard substrates. Deeper in the canyon axis the fauna is dominated by the ophiurid *Ophiomusium lymani* and a species of the burrowing cerianthid anemone.

Figure C6 shows the major faunal components seen during three dives in Heezen Canyon. The wall of this canyon is

mostly composed of a silty substrate and areas of consolidated clay outcrops. It is not nearly as heterogeneous as the wall of Oceanographer Canyon. Two corals, the gorgonian *Acanella arbuscula* and the alcyonacean *Anthomastus grandiflorus*, both of which are found on soft substrates, dominate the shallower part of the wall (850 to 1050 m). Deeper several echinoderms, an *Ophiocantha* sp., *Ophiomusium lymani* and the urchin *Phormosoma placenta* dominate the fauna. The gorgonian *Paramuricea borealis* was common between 1450 to 1500 meters. In the axis *Hyalinoecia artifex* dominated the fauna between 1150 to 1500 meters. The corals seen were *Anthomastus agassizii* and *Desmophyllum cristagalli*, both restricted to hard substrates. From 1500 to 1550 meters *D. cristagalli* dominated the fauna, whereas deeper *Ophiomusium lymani* was dominant.

The fauna on the wall of Corsair Canyon was heavily dominated by coral (Figure C7). These were all corals restricted to soft substrates. The delicate bush-like gorgonian *Acanella arbuscula* was a prominent constituent of the fauna between 600 to 800 meters. From 800 to 1000 meters the fauna was dominated by the corals *Anthomastus grandiflorus* and a species of *Pennatulula*. The wall of Corsair Canyon, as well as that of Heezen Canyon, is not nearly as heterogeneous in terms of substrate variability as that of Oceanographer Canyon. Thus, particular species tend to dominate the taxa, whereas the fauna on the wall of Oceanographer Canyon is

composed of a much more complex assemblage of a variety of taxa and tropic types.

The canyon fauna on the whole tends to follow the trend of increasing importance of echinoderms with depth. The middle depth zone from 650 to approximately 1400 meters is dominated by corals and a variety of other taxa, whereas on the slope it is dominated by fish. This difference could well be due to the greater variety of substrate types and higher nutrient flux available in canyon habitats.

Several other notable exceptions to this trend were also seen. During most of the shallow water DIAPHUS dives a delicate white sea pen (unidentified at this time) was seen. The percent of echinoderms in one dive at the head of Lydonia Canyon is anomalously high. This reflects the large number of individuals of the burrowing ophiuroid *Amphilimna olivacea* seen during that dive. The dive transcript stated that the submersible stayed in one place for a longer time than usual and the ophiuroids started coming out of their burrows. Thus, because of their burrowing habit they could be an important constituent of the shelf fauna that would be overlooked in photographic surveys.

Two exceptions in the deeper part of the study area were one dive at the Deep Water Dumspite #106 and one dive in the deep axis of Hudson Canyon. The fauna seen on dive 666 at DWD-106 was dominated by a small unidentified sea pen. A major component of the fauna seen on dive 594 in the axis of

Hudson Canyon was a large white galatheid crab *Munidopsis rostrata* which was seen only on hard substrates.

Community Analysis and Depth Zonation

The results of the principal components analysis yielded some broad faunal trends that could be related to depth and substrate variability. However, extreme care must be taken in interpretation of this data. The obvious problem with this sort of survey is that samples tend to be concentrated in areas that were not randomly chosen, hence this raises the question of how representative they are of the study area as a whole. This factor is compounded by the problem of species recognition from photographs. Thus, patterns seen may or may not be real in terms of species distribution if two closely related species could not be discerned on the basis of gross morphology.

The data was first run with all dominant taxa included in the data matrix. This analysis resulted in 73% of the variation in the entire sample set being explained by 10 species or species assemblages. The first four end-members of the analysis were monospecific, meaning that the numerically dominant species tended to be independently distributed. In a biological sense this basically means that these species are being controlled by different variables, and do not form a tight interactive assemblage of organisms. The pattern that does emerge is one of gradual replacement of species over depth intervals.

However, three major faunal zones superimposed on several minor ones were identified by the rotated principal components analysis. The shelf and upper slope (100-350 m) samples can be mainly explained by the presence of four species. The middle slope (800-1300 m) samples were dominated by fish, while the deeper slope (1500 m) samples were dominated by three species. The samples from the canyons, on the whole, tend to be composed of a more complex mixture of species, with each species or pair of species being rather independent of the others. Also there are non-consistent variations of assemblages with depth on the canyon walls, which tend to indicate a very patchy distribution.

Two of the dominant taxa, fish and a species of sponge from the genus *Cladorhiza*, were then excluded from the second run; the rationale being that these taxa were either exceedingly dominant or had not been separated into distinct species. These taxa were omitted from the next analysis to ascertain whether they might be obscuring fine scale variation in some of the other components. The first three end-members of this run were monospecific, again meaning that the distribution of the dominant taxa are probably being controlled by different parameters. Sixty-eight percent of the sample variance could be accounted for by the first 10 end-members, with 35% of the variance being explained by the first three monospecific end-members.

The first ten end-members (species or species groupings) are identified in Table IV. Five of these are monospecific, meaning their distribution is independent of all other species in this sample set. Four of the factors are dispecific, being composed of two species whose distributions are similar and hence may be controlled by similar parameters. The other factor was composed of three species whose distributions were similar.

When these ten end-members are listed against depth three major faunal zones are discernible (Table V). However, there are minor replacements within the zones with increasing depth. The shallow samples (100-350 m) are composed of two of these end-members: the monospecific white sea pen (9) which is independently distributed, and the *Cerianthus borealis*, *Cancer borealis* and *Munida valida* assemblage (4). The distributions of these three species tend to coincide, indicating that they may be largely controlled by similar parameters. The middle zone (600-1600 m) is composed of a combination of several end-member groups (2, 3, 5, 6, 7, 8 and 10), both mono and dispecific. This means that there is no recognizable cohesive grouping of organisms (i.e. a community) within this zone. However, one or two of these factors tend to dominate this zone within a given area. The deeper zone (1600 m) is largely composed of two independent end-members, the monospecific *Ophiomusium lymani* (1) and the cerianthid anemone and *Echinus affinis* grouping (7).

These results are not surprising when one views the geographic extend of the survey and the variety of habitats found within the study area. The shelf edge and upper slope environment is fairly uniform consisting of a sandy substrate with shell fragments and occasional coral rubble. On close study of the depth distribution of the four major taxa in the shallow samples, a slight emergence of peak densities with increasing latitude is noted (Figure D1). The white sea pen shows a slightly different depth distribution, when compared to the other three taxa. It shows peak densities at 150-200 meters in the northern canyons and at 200-250 meters in the southern canyons, while *Cerianthus borealis* has a peak density at 150-200 meters in the northern canyons and between 250-300 meters in the southern canyons. *Munida valida* has peak densities between 150-200 meters in both the northern and southern canyons, and *Cancer borealis* peaks between 200-250 meters in the northern canyons and 250-300 meters in the southern canyons. Thus, the white sea pen is probably responding to slightly different environmental parameters when compared to the other three dominant species found in these samples. Whether the slight pattern of emergence with increasing latitude is in response to substrate availability or a variety of other factors cannot be determined at this time.

The fauna of the middle zone (600-1600 m) is much more complex. This zone, also, includes the greatest habitat

variability seen throughout the survey. The fauna of the depths between 800-1300 meters generally consists of two end-member groups, shrimp (2) and the red crab *Geryon quinquedens* and the witch flounder *Glyptocephalus cynoglossus* (5).

Figure D2 shows the depth distribution of *Geryon quinquedens*, which was found in the depth range of 300-1600 meters within our study area. In the south peak densities were encountered at 1200-1250 meters where this crab extensively excavated the semi-consolidated clay of the slope. Peak densities in the north were found at 800-850 meters on the wall of Oceanographer Canyon. The depth range of *G. quinquedens* overlaps with the lower range of the jonah crab *Cancer borealis*, but it was never encountered in as high a density.

Another faunal component of this middle zone is the quill worm *Hyalinoecia artifex* (3), which when it occurred was present in such high densities that it obscured the contribution of any of the other taxa within that sample. It has been pointed out by Grassle et al., (1975) that the taxonomy of *Hyalinoecia* is quite complex, and thus, it is likely that more than one species of this polychaete does exist within the study area. The urchin *Phormosoma placenta* (10) is also found within the middle depth zone. Like *Hyalinoecia* this species tends to numerically dominate the fauna in areas where it is seen. Both of these species tend to have a very patchy distribution, characterized by high dominance in several of the samples and almost complete absence in the other samples.

The dominant taxa at these depths are similar to those reported by Haedrich, Rowe and Polloni (1975). *Geryon quinquedens*, *Glyptocephalus cynoglossus* and *Hyalinoecia artifex* were among the seven top ranking species in the middle zone (393-1095 m) of their trawl study on the slope south of New England. Surprisingly, *Hyalinoecia* was absent from Alvin Canyon in their study, whereas in the present survey three out of five occurrences were in canyons.

The notable exceptions to the species generally found within this middle depth zone are the faunas of the walls of Heezen and Corsair Canyons. The fauna of the upper wall of Heezen Canyon (850-1100 m) is dominated by two corals *Anthomastus grandiflorus* and *Pennatulasp.* (6). These corals are not independently distributed and almost always occur together. Both are restricted to soft substrates. This assemblage is also found on the wall of Corsair Canyon (750-950 m), at 1450 meters in Oceanographer Canyon, and deeper in the axis of Norfolk Canyon (1500-1600 m and 2150-2350 m). The fauna of the wall of Corsair Canyon is mainly composed of two dispecific end-members, the *Anthomastus grandiflorus* and *Pennatula* sp. assemblage (6) and two other corals *Acanella arbuscula* and a sea pen that may be *Distichoptilum gracile* (assemblage 8). Both assemblages are restricted to soft substrates. A soft coral resembling *Acanella arbuscula* was also seen at 2300 meters at DWD-106 and from 1750 to 1900 meters in an area south of Norfolk Canyon. *Anthomastus grandiflorus*,

Pennatula sp. and *Acanella arbuscula* all show a general pattern of emergence with increasing latitudes (Figures D3 and D4). Voucher specimens of individuals from both the southern and the northern populations are required to determine if they are in fact composed of the same species. Additionally, without more detailed information on the fine scale substrate and current regimes, it is impossible to determine what factors are controlling the distribution of these corals.

The fauna of the deeper portion of the study area (1600 m) is dominated by two end-member assemblages, the ophiurid *Ophiomusium lymani* (1) and the urchin *Echinus affinis* and a cerianthid anemone (7). These two end-members are independently distributed. Qualitative observations made during the photographic review note that although all three of these species occur in the same area, when *Ophiomusium lymani* was particularly abundant the other two were not. Conversely, where the cerianthid anemone was locally abundant *O. lymani* was not. *O. lymani* is found at depths ranging from 1100 to 2500 meters, with peak abundances near 1800 meters. This ophiuroid was frequently seen at the base of sea pens and gorgonian colonies. It is not known if the ophiuroid is merely responding to structural heterogeneity in its environment or whether there is a beneficial association between the two. The burrowing cerianthid is found at depths ranging from 600 to 3200 meters, with peak

abundances at approximately 1800 meters. It is also likely that more than one species of cerianthid occurs within the study area, however, this would not be discernible from the photographs. *Echinus affinis* is found between 1400 to 3000 meters within the study area, with peak densities at 1800 meters in the northern region and somewhat deeper in the south. However, the coverage is too sparse to determine the full extent of its depth distribution.

Corals

Corals (primarily alcyonarians) were seen at all depths throughout the study area. Figure E1 shows the depths where corals were seen during individual dives, as well as the availability of hard substrates. These corals include a wide variety of types, sizes and growth forms. Both scleractinians (hard corals) and alcyonarians (soft corals) were seen. The scleractinians range from delicate solitary cup corals to large branching colonies. The alcyonarians range from small nondescript sea pens to massive branching colonies several meters in height. The following is a brief description of most of the dominant or more striking corals seen during the survey.

Scleractinians

Dasmosmilia lymani is a pale orange fairly delicate solitary coral that reproduces by longitudinal splitting.

Its reported geographic distribution is from Massachusetts to Florida at depths ranging from 48 to 366 meters. In this study it was observed on the continental shelf between Baltimore and Hudson Canyons and on the shelf near the head of Hudson Canyon. When it occurred *D. lymani* was found in extremely high density, probably as a result of its reproductive mode, with dead individuals forming a considerable mat of coral rubble on the surface. This coral is found on soft substrates.

Desmophyllum cristagalli is a pale pink large horn-shaped solitary coral always found attached to hard substrates. This species was found only in canyons where outcrops provided a suitable habitat. Its geographic distribution is from Nova Scotia to Brazil at depths ranging from 155 to 1939 meters. During this survey *D. cristagalli* was observed attached to outcrops at depths ranging from 1000 to 1900 meters. It frequently occurred in dense concentrations on underhangs, with a downward facing orientation which probably protects the polyp from sediment loading.

Flabellum alabastrum is a large salmon-colored solitary cup coral. It is found on soft substrates from Georges Bank to Cape Hatteras at depths ranging from 400 to 1200 meters. In the study area it was found in both canyons and on the slope from 600 to 2500 meters. Many of the individuals seen were probably *F. alabastrum*, however, some of the deeper ones may well have been *F. angularis* or *F. moseleyi*.

Lophelia prolifera is a large pale-pink anastomosing colonial hard coral that frequently forms deep-sea coral banks (Stetson, Squires and Pratt, 1962). Its geographic distribution is from Nova Scotia to Brazil at depths ranging from 95 to 1000 meters. *Lophelia* banks have best been studied on the Blake Plateau where they closely follow the 800-meter isobath (Steve Cairn, personal communication). A dense stand of *Lophelia* was observed on the west wall of Oceanographer Canyon at 1100 meters. However, extensive *Lophelia* rubble was also found on the wall of that canyon at depths ranging from 700 to 1300 meters.

Alcyonarians

Paragorgia arborea was the most spectacular soft coral seen within the study area. It is a massive red branching gorgonian with large polyps and is restricted to hard substrates. It was seen in Norfolk Canyon between 400 and 600 meters and in Oceanographer Canyon between 900 and 1100 meters. *P. arborea* has also been reported from Baltimore Canyon (specimen at the Smithsonian) and the northeast tip of Georges Bank in a region known to local fishermen as "The Trees", where it apparently provides a rich habitat for commercial fish species.

Anthomastus grandiflorus is a bright-red low growing alcyonacean restricted to soft substrates. This species was found throughout the study area, with highest densities

occurring in the canyons. In the northern canyons it was found at depths ranging from 700 to 1500 meters, whereas in the southern canyons it was found from 1500 to 2200 meters (Figure D3). *A. grandiflorus* was frequently seen in areas where a species of *Pennatula* was also common.

Anthomastus agassizii is a bright-red mushroom-shaped alcyonacean restricted to hard substrates. It was found from Corsair Canyon to Hudson Canyon at depths ranging from 750 to 1800 meters. *A. agassizii* was not seen in Norfolk Canyon even though adequate substrates and depth ranges were covered. A similar coral, *Trachythela rudis*, was seen in Oceanographer and Heezen Canyons. Its growth form and habit is very similar to *A. agassizii* but its coloration is brilliant purple as opposed to red, and it is slightly smaller than *A. agassizii*.

Paramuricea borealis is a large yellow irregularly branching gorgonian restricted to hard substrates. It was found from Corsair Canyon to as far south as DWD-106 at depths ranging from 700 to 2200 meters. Again, as with *A. agassizii*, it was not found in Norfolk Canyon despite coverage of suitable substrates and depth range. This species is known to occur in a variety of colors ranging from white to yellow to pink and to purple. Some colonies seen on the Reykjanes Ridge, in fact, had two colors occurring within the same colony (unpublished photographs). Frequently five to six individuals of the ophiuroid *Asteronyx loveni* were seen coiled in the branches of a *P. borealis* colony.

Pennatula is a large purple plume-like sea pen restricted to soft substrates. This sea pen was found throughout the study area, but it appeared in high concentrations only in the canyons. As with *Anthomastus grandiflorus* it was found at shallow depths in the northern canyons (600 to 1500 m) and deeper in the southern canyons (1500-2400 m). Again, a pattern of emergence is indicated but the geographic coverage is too sparse to warrant a conclusive generalization. Three species of *Pennatula* occur within the study area, *P. aculeata*, *P. grandis* and *P. borealis*. However, the taxonomic differences between the three species are not gross enough to be readily discerned in photographs. Hence, we identified the pennatulids seen as *Pennatula* sp. It is quite likely that most of these pennatulids are *P. aculeata* since this species is common and has been collected throughout the study area.

Acanella arbuscula is a pale-pink finely branched bush-like coral usually restricted to soft substrates. It is known to occur all along the eastern sea coast at depths ranging from 425 to 2875 meters. In the study area its depth range was from 600 to 1300 meters in the north and 1500 to 2000 meters in the south. The growth habit of the northern form was finer and denser than that of the southern form. This difference may indicate that the southern form could be a totally different species. However, the different growth forms might also be the result of habitat differences, such as current velocity and nutrient availability. Thus, it is

not known whether the southern and northern forms are the same species or closely allied species.

Acanthogorgia armata is a fluffy white to pink soft coral restricted to hard substrates. Approximately four polyps branch off from the main axis at any given level giving the colony a very delicate bushy appearance. This coral was found throughout the canyons in the study area at depths ranging from 600 to 2500 meters. A stouter yellow gorgonian with large polyps was frequently found directly next to an *A. armata* colony. At present the species identification of this coral or whether there is an association between it and *A. armata* is not known.

Eunephthya fruticosa is a translucent white gorgonian with branches and polyps radiating out from a central axis. This species presented a major problem in species identification, because preserved specimens of *E. fruticosa* are opaque grey and broccoli shaped. It was found in the southern region of the study area at depths ranging from 2300 to 3100 meters. A similar but shorter and denser coral was seen in Corsair and Heezen Canyons between the depths of 600 to 1200 meters. This coral is probably *E. florida*, which is known to be common in that area.

Anthoptilum grandiflorum is a large fluffy plum colored whip with polyps arranged in oblique rows along its axis. Six individuals of this species were seen in the northern region of the study area between the depths of 900-2200 meters.

Balticina finmarchica is a pale slender whip with polyps arranged in oblique rows along its axis. Six individuals of this species were seen in the northern region of the study area between the depths of 900-2200 meters.

Virgularia mirabilis is a stiff pen with compact polyps on each side of the main axis. Seven specimens of this sea pen were seen on the slope between Baltimore and Norfolk Canyons at depths from 1500 to 1800 meters. Each pen seen had an associated ophiurid coiled around its central axis.

Kophobelemnion stelliferum is a short stiff sea pen with large polyps coming out from the central axis. This pen was found throughout the study area at depths ranging from 1300 to 1800 meters and was also seen at comparable depths in the Hatteras Canyon region.

White sea pen was similar to a very fine *Pennatula*. It was found in great densities on the shallow water dives throughout the study area at depths ranging from 100 to 300 meters. At this time its species identification is now known.

Throughout the dives small short non-descript sea pens were observed at all depths within the study area. Without voucher specimens identification of these pens cannot be made.

Distribution of Corals

A number of coral species were seen fairly consistently throughout the study area. Positions of their known occurrences are mapped on Figure E2. It can be seen that coral species requiring soft substrates have a much broader distribution than those restricted to hard substrates. Small

non-descript sea pens (not identified to species level) are found throughout the study area.

Acanella arbuscula, *Pennatula* sp. and *Flabellum alabastrum* were found on the deeper part of the continental slope south of Norfolk Canyon. In the axis of Norfolk Canyon the coral population is dominated by *Flabellum alabastrum*, *Pennatula* sp. and *Anthomastus grandiflorus* on the soft substrates, with occasional occurrences of *Acanthogorgia armata* and *Desmophyllum cristagalli* where outcrops were exposed. Deeper at the mouth of the canyon *Eunephthya fruticosa* was seen along with the soft substrate corals. On the slope just south of Baltimore Canyon *Acanella arbuscula*, *Pennatula* sp. and *Flabellum alabastrum* were seen.

White fluffy sea pens were the only corals found in the heads of Carteret and Toms Canyons. Deeper at Deep Water Dumpsite #106 populations of *Eunephthya fruticosa*, *Pennatula* sp. and *Anthomastus grandiflorus* were seen. An outcrop in this area provided the necessary substrate for *Paramuricea borealis*, *Acanthogorgia armata*, *Desmophyllum cristagalli* and *Anthomastus agassizii*.

Only sea pens were found in the main part of Hudson Canyon. *Eunephthya fruticosa* and sea pens were found in the deeper portion of this canyon. Corals observed in a number of dives on the deep continental slope near Alvin Canyon include *Acanella arbuscula*, *Flabellum alabastrum*, *Acanthogorgia armata*, *Paramuricea borealis* and sea pens.

The shallow water dives in the head of Veatch Canyon again revealed high concentration of the white sea pen. Numerous corals were seen in several photographic transects in Oceanographer Canyon. *Paramuricea borealis*, *Desmophyllum cristagalli*, *Anthomastus agassizii* and *Acanthogorgia armata* were found on boulders or outcrops, while *Acanella arbuscula* and *Flabellum alabastrum* were found on the soft substrates in this canyon.

Sea pens were seen in the head of Lydonia Canyon, while *Paramuricea borealis*, *Anthomastus agassizii* and *Desmophyllum cristagalli* were seen in selected slides of some early dives in the deeper parts of this canyon.

A number of dives in Heezen Canyon revealed many corals. *Pennatula* sp., *Anthomastus grandiflorus* and *Acanella arbuscula* were found on soft substrates within this canyon, while *Paramuricea borealis*, *Desmophyllum cristagalli* and *Anthomastus agassizii* were seen on outcrops.

Corals were also abundant in Corsair Canyon. *Anthomastus agassizii*, *Acanthogorgia armata*, *Paramuricea borealis* and *Desmophyllum cristagalli* were seen on outcrops in this canyon, while *Pennatula* sp., *Acanella arbuscula* and *Flabellum alabastrum* were seen on soft substrates.

Corals that were rarely encountered during the survey are mapped on Figure E3. The most striking of these is *Paragorgia arborea* which was seen on several pictures obtained from a dive in the shallow part of Norfolk Canyon.

This species was also seen in selected slides and a film from Oceanographer Canyon. Three whips *Virgularia mirabilis*, *Acanthoptilum grandiflorum* and *Balticina finmarchica* were seen in the study area, as well as species of *Umbellula* and *Radicipes*. *Dasmosmilia lymani* was found on the continental shelf between Wilmington and Hudson Canyons. *Eunephthya florida* was found in Heezen and Corsair Canyons.

A detailed mapping of the corals is possible for those dives where we have accurate dive track information.

The locations of dominant coral species seen during dives 808, 809, and 810 in Norfolk Canyon are mapped in Figure E4. *Acanthogorgia armata*, *Desmophyllum cristagalli* and *Flabellum alabastrum* are present on outcrops shallower than 1200 meters. During dive 809 sea pens, *Pennatula* sp. and *Anthomastus grandiflorus* are found on the soft substrate. Dive 810 was the deepest dive in this area and many individuals of *Pennatula* sp. and *Anthomastus grandiflorus* were seen, while *Flabellum alabastrum* and *Eunephthya fruticosa* were less common. Except for *E. fruticosa* these corals are restricted to soft substrates.

Figure E5 is a map of the corals occurring between Baltimore and Hudson Canyons. It shows the location of corals seen in the heads of Toms and Carteret Canyons as well as those seen at DWD-106. As was previously mentioned, the white sea pen and other undifferentiated sea pens were seen in the shallow region. *Eunephthya fruticosa*,

Anthomastus agassizii, *Paramuricea borealis*, *Pennatula* sp. and *Acanthogorgia armata* occurred at approximately 2250 and 2500 meters depth in this area.

The location of coral populations seen on the continental slope near Alvin Canyon is shown in Figure E6. *Acanella arbuscula*, *Anthomastus agassizii*, *Paramuricea borealis*, *Flabellum alabastrum* and sea pens were found in this area of mixed substrates.

Dives in Oceanographer Canyon (Figure E7) covered the canyon axis and west wall, revealing a pattern of coral distribution that is somewhat different from that seen farther north in Heezen Canyon. *Desmophyllum cristagalli*, *Anthomastus agassizii* and *Paramuricea borealis* were found in the axis of the canyon while *P. borealis*, *Acanthogorgia armata* and *A. agassizii* occurred on cobbles and glacial erratics on the canyon wall. Some individuals of *Acanella arbuscula* were seen on the soft substrate of the canyon wall.

The dives in Heezen Canyon (Figure E8) provide good comparative coverage in both the canyon axis and on the canyon wall. Corals restricted to hard substrates, such as *Desmophyllum cristagalli*, *Anthomastus agassizii* and *Paramuricea borealis* were seen on outcrops in the canyon axis, while *Pennatula* sp., *Acanella arbuscula* and *Flabellum alabastrum* were seen on the soft substrate of the canyon floor. On the canyon wall soft substrate species such as

Acanella arbuscula, *Pennatula* sp., *Anthomastus grandiflorus* and *Flabellum alabastrum* were seen.

Numerous corals were seen during dive 781 in Corsair Canyon near the northern limit of the study area. This dive provides coverage of a transect from the axis up the canyon wall. *Acanella arbuscula*, *Pennatula* sp., *Anthomastus grandiflorus* and *Flabellum alabastrum* were seen on the soft substrates, while *Paramuricea borealis* and *Anthomastus agassizii* were restricted to occasional outcrops.

Coral Communities

The most striking result of a rotated principal components analysis on the corals in the data matrix is that the coral assemblages exhibit very little cohesive structure. The general category of sea pens was again excluded from this analysis because of the problems with species recognition discussed in the preceding section. Eighty-six percent of the variance within the data matrix can be explained by the first ten end-members (Table VI). Seven of these end-members are monospecific, while three are dispecific. The general interpretation of the results of this analysis is that the distributions of most of these deep-sea corals are being controlled by different parameters. This trend was also found in the community analysis of the total fauna, namely a shallow zone dominated by one species and a general tendency of some species to become shallower with increasing latitude.

This pattern of emergence cannot be explained without a rigorous examination of the factors that control the distribution of these organisms.

Study of some of the ten end-members elucidates several of these factors. End-member 4 is composed of two species, the alcyonacean *Anthomastus agassizii* and the gorgonian *Parmuricea borealis* both of which are restricted to hard substrates. They are dominant deeper in the northern canyons, but are not found in the southern canyons even though suitable substrate (outcrops) does occur at comparable depths in Norfolk Canyon. *Acanthogorgia armata* (8) and *Desmophyllum cristagalli* (9) are also restricted to hard substrates. In Norfolk Canyon both of these species co-occur on the same outcrops. In the northern canyons *Acanthogorgia armata* is most prevalent on the glacial erratics occurring on the wall of Oceanographer Canyon, while *Desmophyllum cristagalli* is restricted to the underhangs of the more massive outcrops found in the axes of all three northern canyons (Table VII). These four species do have at least one thing in common, the fact that they are restricted to hard substrates and are therefore found mainly in canyon areas. However, without more detailed information on some of the other factors, such as current activity, the specifics of these overlapping but discontinuous distributions cannot be interpreted.

Anthomastus grandiflorus and *Pennatula* sp. (6) and *Acanella arbuscula* (3) are restricted to soft substrates. Their distributions have been discussed in detail in the community analysis of the total fauna. *Flabellum alabastrum* (5) and *Distichoptilim gracile* (1) are both found on soft substrates and are present throughout the deeper part of the study area. It should be mentioned that the distribution of both of these species may, in fact, be composites of more than one species. Both are rather small making detailed identification from photographs, on species characteristics, impossible. One interesting assemblage is composed of *Eunephthya fruticosa* and *Pennatula* sp. (10). This assemblage is restricted to the deeper parts of Hudson and Norfolk Canyons. Abundant populations of large individuals of *Eunephthya fruticosa* were found only in the deeper part of Hudson Canyon.

In general the corals in our study area do not occur as discrete communities, but rather tend to co-exist in some regions and not in others. The corals found on hard substrates are restricted to canyons where outcrops and boulders provide suitable habitats. Several of the coral species whose distributions are similar within our study area are recognized as members of dispecific assemblages. It might be inferred that the habitat requirements of these species are quite similar. Closer examination of the coral

populations found on the northern canyon wall dives indicate that canyons offer a variety of habitats. Seven species of corals are dominant between 650 and 1550 meters on the wall of Oceanographer Canyon, three monospecific and two dispecific assemblages. The depth interval between 650 to 950 meters is dominated by *Acanthogorgia armata* (8) which is found on numerous glacial erratics and coral rubble. Between 950 and 1350 meters *Acanella arbuscula* (3), *Anthomastus agassizii* and *Paramuricea borealis* (4) predominate. *Acanella arbuscula* is found on the soft substrate, while the other two corals are restricted to the glacial erratics, outcrops and coral rubble occurring in this area. Slightly deeper *Pennatula* sp. and *Anthomastus grandiflorus* are found on the soft substrate. The surface sediments on the wall of Corsair Canyon are mostly composed of silt and consolidated clay. The corals here are dominated by species requiring soft substrates. The same is true for the wall of Heezen Canyon, with the exception of the deeper part. Here outcrops occur and the coral fauna is dominated by *Paramuricea borealis* and *Anthomastus agassizii*. A closer examination of the canyon walls might yield distinct assemblages, but at this time the data is not extensive enough to warrant this type of analysis.

Faunal Similarity

The faunal similarity analysis yielded somewhat

ambiguous results. The percent of faunal overlap between depth intervals was frequently amplified or decreased by patchy distribution of the organisms and by substrate variability. For example, faunal similarities between adjacent 50-meter depth intervals is fairly low in shallow water (100-300 m). It ranges from 0% to 50% but is frequently as low as 10%. This phenomena is probably a reflection of the rather restricted depth zones of many of the species found in the shelf faunal province. This situation is further complicated by the fact that a large geographic area is contained within a depth interval and thus that depth interval is more likely to include a variety of gradational substrate types. Percent faunal similarity is somewhat higher, frequently from 50% to 80%, between adjacent dives within a depth interval. However, there is a marked difference between the fauna of the southern area when compared with that of the northern area (0% to 30%). The southern shelf province is dominated by *Munida valida* and the white sea pen, while the northern province shows much greater variability. This province is dominated by the white sea pen, a small pink amphipod, a shrimp, and the ophiurid *Amphilimna olivacea*. A pueblo community as defined by Warne et al. (1978) was seen at a depth of 250 meters in Carteret Canyon. Dominant taxa were *Cancer borealis*, occasional lobsters and fish. A similar pueblo community was seen at a depth of 150 meters in Veatch Canyon.

Between the depths of 300 to 500 meters on the slope south of Baltimore Canyon faunal similarity is extremely high between adjacent 50-meter depth intervals (80% to 90%). These high values are due to the overwhelming presence of *Hyalinoecia artifex*. This quill worm has a patchy distribution and is extremely abundant where it occurs. It thus tends to obliterate any trend found in the other fauna. Percentage similarity, between adjacent 50-meter depth intervals, is also uniformly high between 850 to 1300 meters (50%-80%). This high degree of overlap is due to the dominance of the fish found throughout this zone. Percentage similarity is again high between adjacent 50-meter depth intervals in the 1550 to 1800 meter range (70%-90%). This is due to the presence of one dominant species, *Ophiomusium lymani* throughout this range. Faunal similarities between dives in the depth range of 1700 to 1900 meters are also uniformly high (70% to 80%), being due to the ubiquitous presence of *Ophiomusium lymani*.

However, at intermediate depths comparisons between slope and canyon fauna yield a low percentage faunal similarity (10% to 20%). The amount of species overlap between adjacent depth intervals in a canyon is exceedingly variable (3% to 90%). These results again point to the fact that canyons provide rather unique habitats for their faunal constituents. The high degree of environmental heterogeneity found on canyon walls provides opportunities for

the coexistence of a large variety of different epifaunal species and tropic types. The slope, on the other hand, does not provide as heterogeneous an environment and therefore has similar fauna over wider latitudinal and bathyal ranges.

Faunal Associations

Several types of faunal associations were observed during this survey. However, probably many more faunal associations exist between the animals which are not apparent in photographs. Examples of this might be the reported association between a small shrimp and the coral *Paragorgia arborea* or the association between cleaner shrimp and fish in pueblo communities. This is, additionally, complicated by the fact that associations are usually manifested behaviorally, which can be determined only by direct visual observation over a period of time.

One common association observed was that of the ophiurid *Asteronyx loveni* and corals. Most instances of this association were probably not discernible on photographs, due to the fact that *Asteronyx* is frequently tightly coiled within the inner branches of gorgonian colonies. Additionally, in relation to the association between the coral *Acanella arbuscula* and *Asteronyx loveni* the coloration of the two is similar enough to prevent recognition of the ophiurid. This

association appears to be obligatory because no individuals of *Asteronyx* were ever found alone.

Another association noted during this survey was the cooccurrence of *Ophiomusium lymani* with several gorgonians. This ophiurid was frequently found at the base of the coral. Whether or not this relationship is obligatory is not known. *Ophiomusium lymani* may merely be responding to structural heterogeneity in its environment. However, frequently as many as four were found at the base of the gorgonians. Another association was observed between *Collosendeis colossea* and *Paramuricea borealis*. Individuals of this pycnogonid were frequently seen climbing on the coral colonies. Whether this indicated instances of predation, a cleaning association, or were mere coincidence is not known.

An association that was noted during the shallow water dives of this survey was that of the large burrowing anemone *Cerianthus borealis* and small individuals of the jonah crab *Cancer borealis*. These jonah crabs were frequently found around the base of the anemone tubes. Additionally small fish exhibited a similar relationship with this anemone. It is possible that juvenile fish and crabs utilize the base of the anemone for protection.

CONCLUSIONS

On the whole the analysis of the submersible photographs identified submarine canyons as providing rather unique habitats for their faunal constituents. They provide a variety of substrate types, and are implicated as being areas of increased current activity and nutrient enrichment. Our analysis supports the evidence that suggests the existence of three major faunal provinces on the continental margin. The shelf and shelf-break area is dominated by crustaceans and fish. While fish dominate the upper portion of the slope and echinoderms dominate the lower slope. This trend was somewhat obscured within canyons, attesting to the greater environmental heterogeneity afforded by canyons. The canyon fauna is unique in that it is frequently composed of high percentages of sessile organisms such as corals and sponges. At intermediate depths filter-feeding corals tend to dominate the faunal assemblage. Another finding was that canyon epifauna was generally more abundant than slope epifauna at comparable depths.

Within these three major depth zones gradual faunal replacement with increasing depth was observed. Shallow water species tended to have narrower depth ranges than deep water species. These ranges may be determined by the availability of suitable substrates rather than by temperature variability or barometric pressure. Another trend noted was that of the gradual emergence of some species with increasing latitude.

This again may be related to substrate availability. This conclusion is somewhat tenuous due to the lack of correlative substrate characteristics and environmental parameters of the areas viewed.

The nutrient rich shelf supports a variety of trophic types. However, the fauna is dominated by carnivores and scavengers (crabs and fish). The upper slope which tends to be rather homogeneous with regard to substrate is also relatively nutrient rich. The fauna here again is dominated by carnivores and scavengers namely, the red crab *Geryon quinquedens* and fish. The lower slope is slightly more heterogeneous in terms of substrate availability and is rather nutrient poor. This region is dominated by deposit-feeding echinoderms. This pattern is somewhat changed on the walls of canyons. Here the fauna is frequently dominated by sessile filter-feeding organisms, namely corals and sponges. The presence of filter-feeders in canyons and not on the slope may be explained by the postulated nutrient enrichment of canyons and availability of hard substrates.

In general, no discrete cohesive faunal assemblages were identified by the community analysis. Rather the results indicate that most of the dominant species in the study area are independently distributed. This is concluded from the fact that most end-members of the factor analysis were monospecific. Intensive study of a more restricted geographic area might reveal cohesive localized communities,

but when viewed over a wide geographic area such relationships are obscured. In effect, this means that the factors controlling the distribution of the species are slightly different such that each species cues in to slightly different specific environmental parameters. At this time the limited information, such as can be discerned from a study of photographs, does not allow elucidation of these differences. Hopefully the controlled sampling of the field program will enable determination of some of the factors responsible for the variations seen in the data set.

ANTICIPATED ENVIRONMENTAL IMPACT OF OCS RESOURCE DEVELOPMENT

Assessments of the possible environmental impact of OCS resource development, at this point, would be exceedingly premature. The inadequate historical data base does not permit a detailed evaluation of the environmental parameters that may be responsible for many of the variations seen in the distribution of the epifauna. The lack of correlative fine scale environmental data hampers interpolation of results from one area to another. Hopefully, by correlating fine scale salinity, temperature and substrate characteristics with the abundance and distribution of epifauna, in the field program, some of the important environmental parameters can be elucidated.

The results have identified canyons as unique habitats, particularly for corals and other filter-feeding organisms. It should be noted that these organisms can be considered as potential environmental "indicators". As filter-feeders they are directly tied to water column characteristics for their nutrients. Thus, any development of resources on the OCS that alters the characteristics of the water (i.e. drilling increasing the amount of suspended particles or oil spills decreasing the primary productivity) could potentially increase coral mortality. Once coral communities, in a specific area, have been located and identified they can be revisited and used as "indicators" of environmental disturbance.

SUMMARY

For the historical coral report all available submersible dives on the mid- and north-Atlantic continental margin were reviewed. Particular emphasis was placed on the canyons found within this area. The depths studied ranged from 100 to 3200 meters.

1. Corals were found at all depths within the study area. Particularly high concentrations and more diverse assemblages were found in the northern canyons. Several of the species exhibited emergence with increasing latitude while others did not.

2. Three major depth zones were identified. The shelf and shelf-break region was dominated by crustaceans and fish. The upper slope was dominated by fish, while the lower slope was characterized by high concentrations of echinoderms. Individual species had more restricted depth ranges within these zones. Gradual faunal replacement with depth was observed.

3. No discrete faunal assemblages were identified. Community analysis indicated that the distributions of the dominant taxa were independent. This implies that the factors controlling each of these organisms are slightly different.

4. Faunal densities were highest on the shelf and at the slope-continental rise boundary. In general higher faunal densities were noted in the canyons than on the slope. This supports the hypothesis that canyons are areas of nutrient enrichment.

5. Canyon walls were identified as unique habitats. They provide a variety of substrate types which in turn determines the distribution of various taxa. Sessile species that require hard substrates were restricted to canyon areas. Canyons also support a greater variety of trophic types than does the adjacent slope.

6. Several types of faunal associations were noted. The most obvious was the occurrence of the ophiurid *Asteronys loveni* in gorgonian colonies. This ophiurid was always seen tightly coiled in the branches of several species of coral.

Another association was that of *Ophiomusium lymani* frequently occurring at the base of coral colonies. Another type of association observed involves the anemone *Cerianthus borealis*. Small individuals of *Cancer borealis* and fish were frequently found at the base of this anemone. Possibly these juveniles utilize the anemone for protection.

7. The results of this study do indicate that canyons are unique habitats. However, the inadequacies of the historical data base do not permit adequate assessment of the factors controlling the distribution of the faunal constituents. Hence, it would be extremely tentative to attempt to interpolate the results to assessing environmental impact. Hopefully, the field program will enable elucidation of some of these factors.

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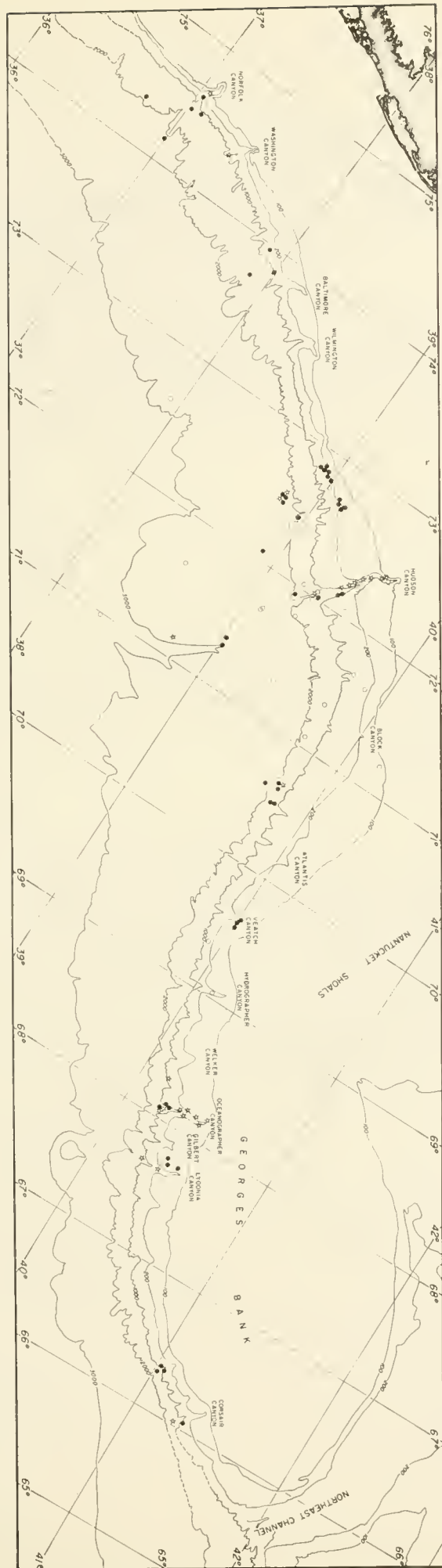
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Figure A-1.

Map of submersible dives and camera lowerings along the Mid and North Atlantic Continental margin reviewed for the historical data survey.

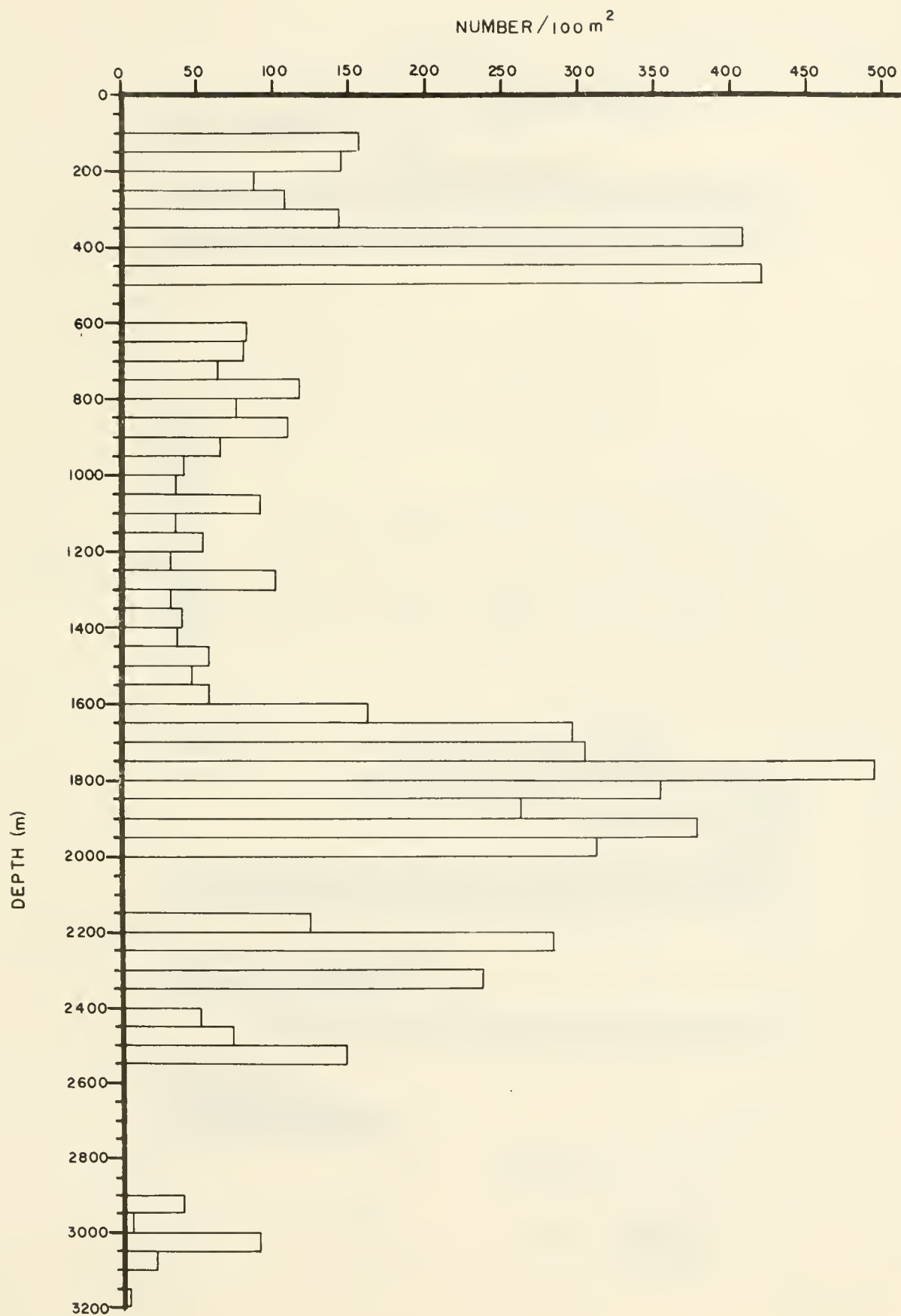
- Quantitative Data
- Camera lowerings
- ☆ NMFS and Qualitative Data



A-63.

Figure B-1.

Histogram of the total faunal density standardized to the number of individuals per 100m^2 for 50 meter depth intervals.



A-65.

Figure B-2.

Histogram of the total faunal density in canyons
versus slope standardized to the number of individuals
per 100m^2 for 50 meter depth intervals.

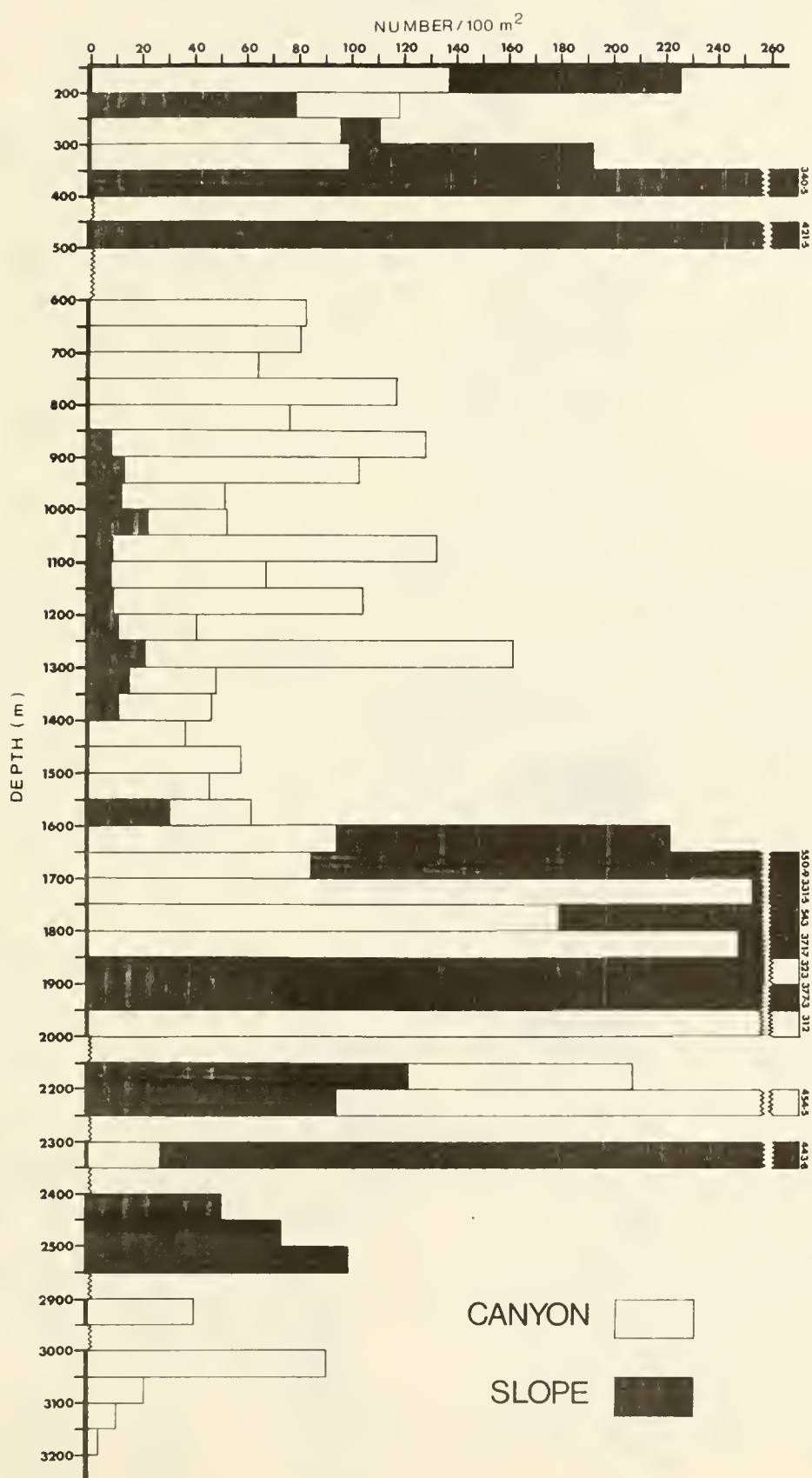
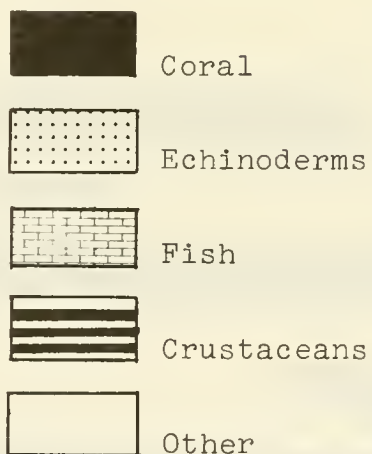


Figure C-1.

Map showing the relative percentages of major faunal groups for each dive.



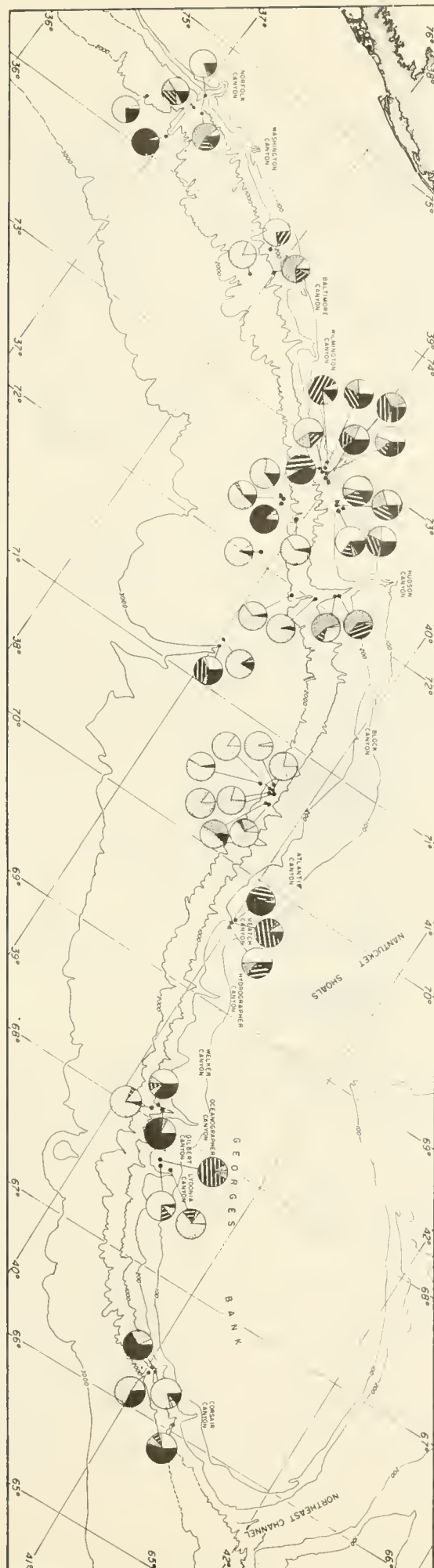
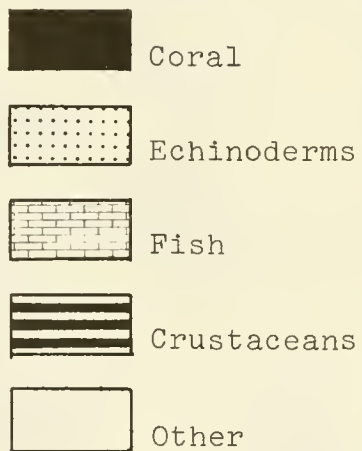


Figure C-2.

Map showing the relative percentages of major faunal groups on the continental slope south of Baltimore Canyon for 50 meter depth intervals.



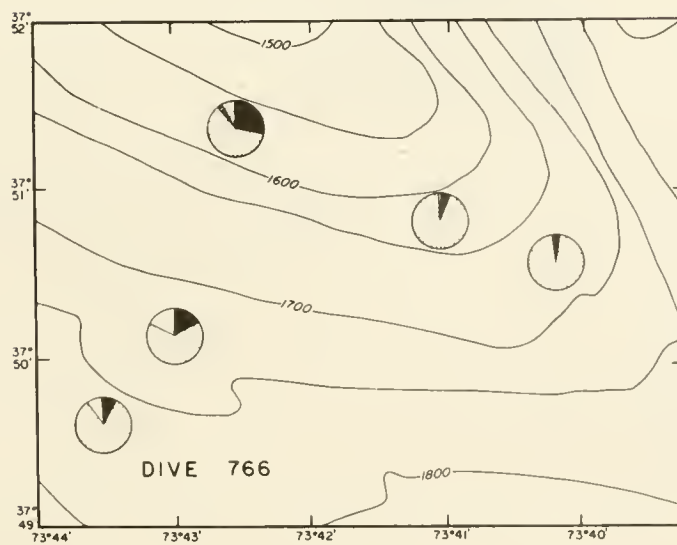
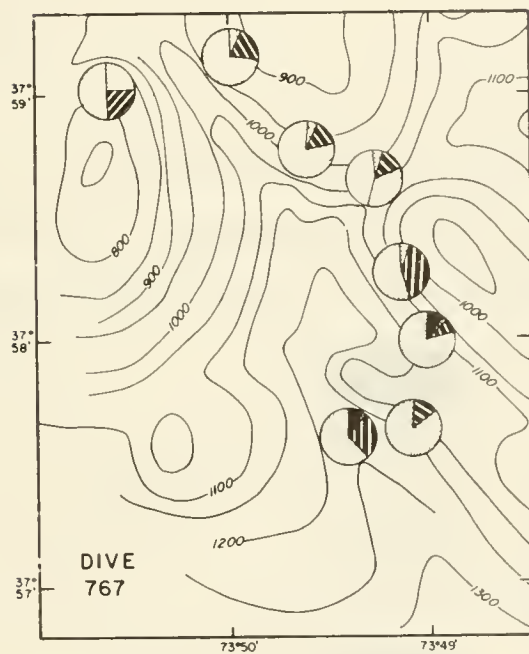
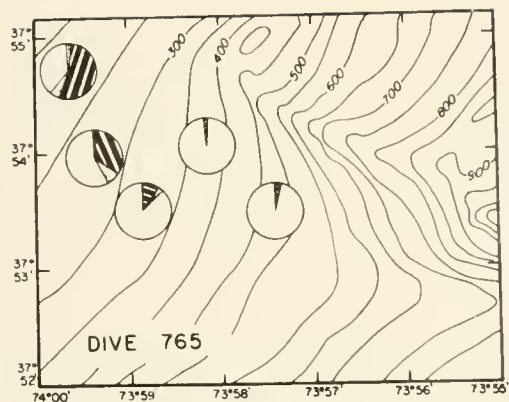
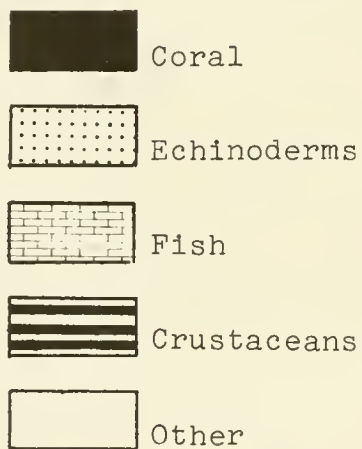


Figure C-3.

Map showing the relative percentages of major faunal groups on the continental slope north of Norfolk Canyon for 50 meter depth intervals.



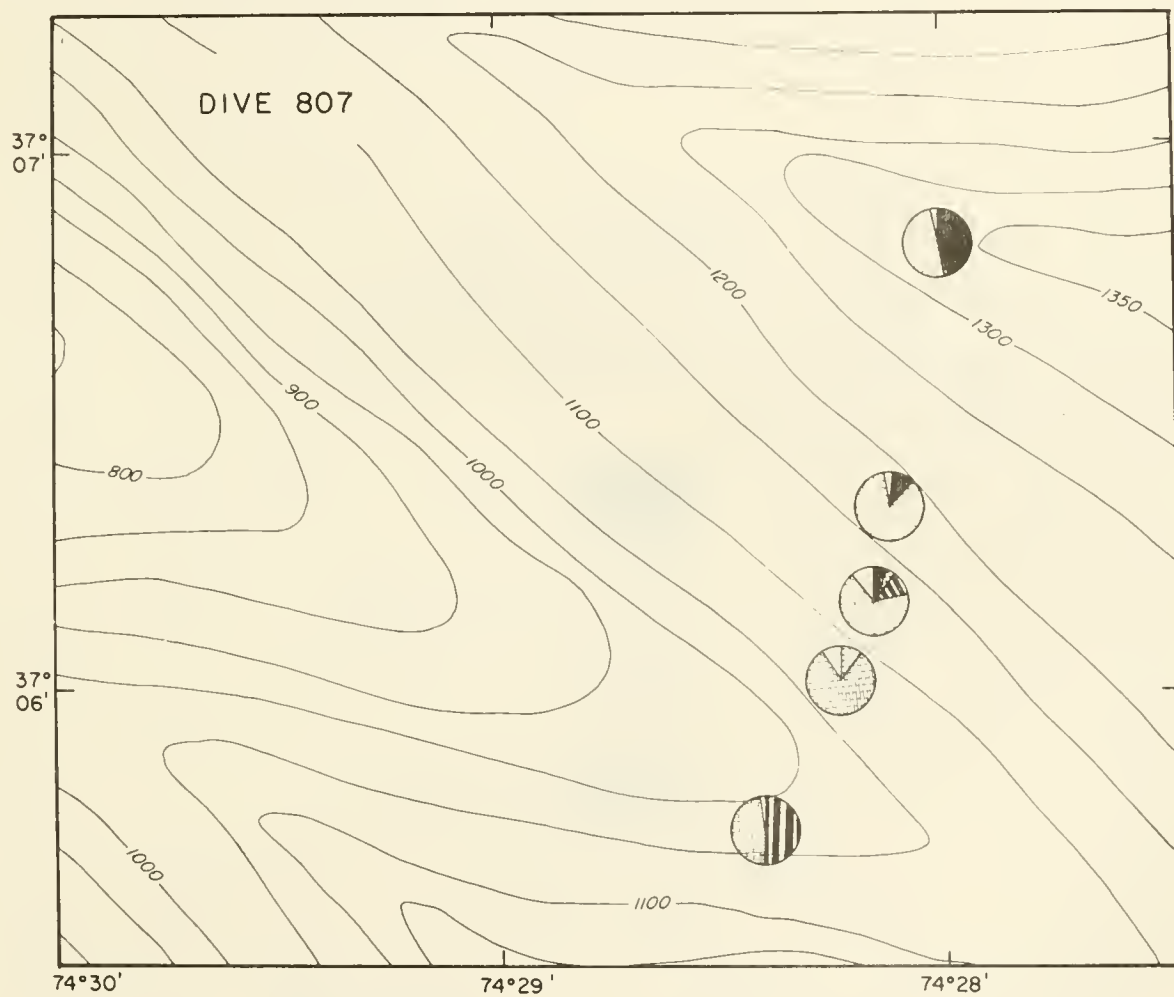
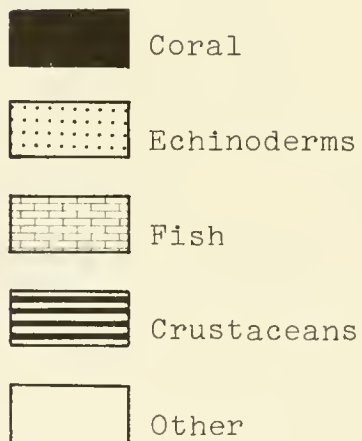


Figure C-4.

Map showing the relative percentages of major faunal groups in Norfolk Canyon for 50 meter depth intervals.



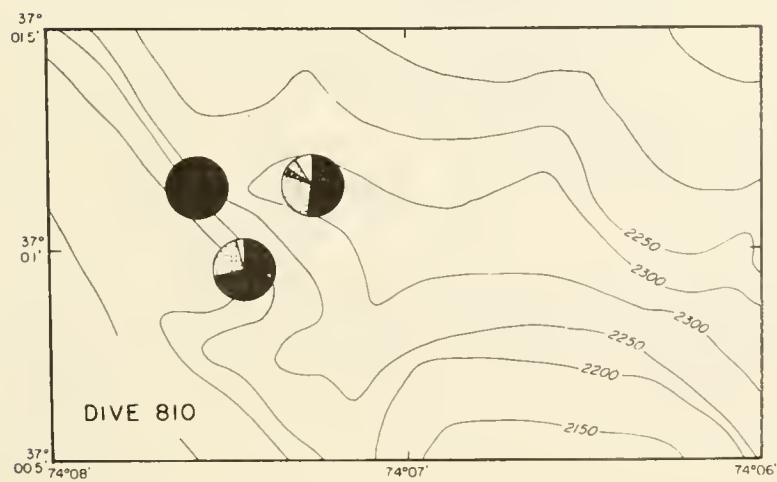
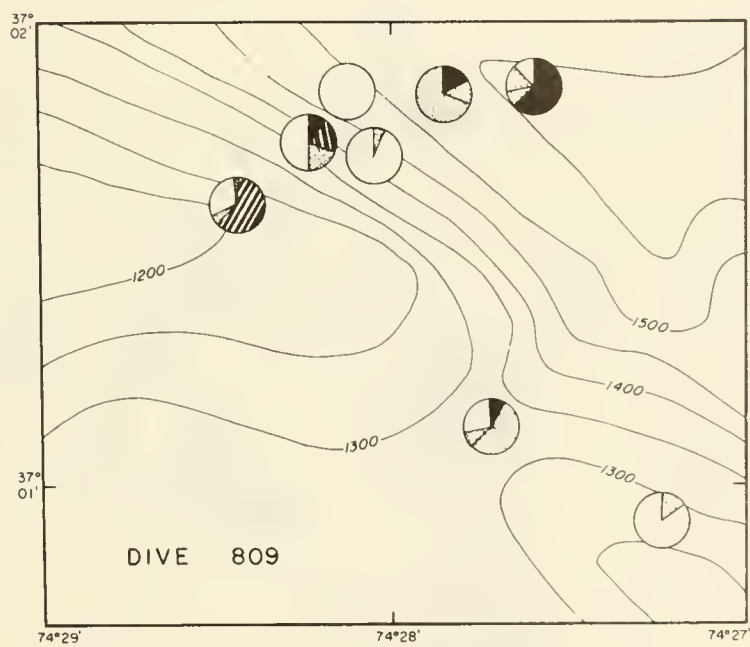
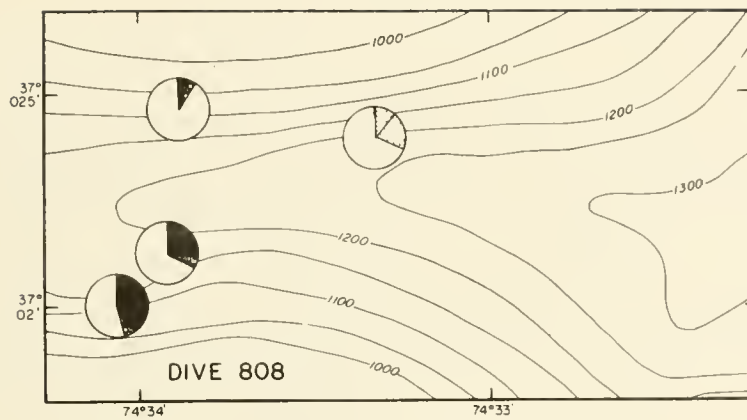
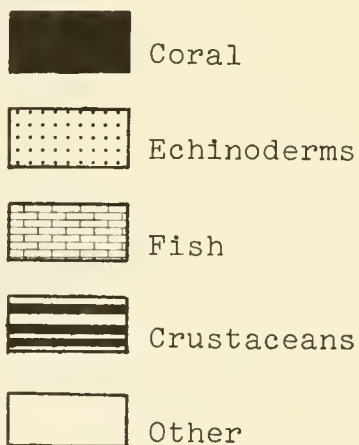


Figure C-5.

Map showing the relative percentages of major faunal groups in Oceanographer Canyon for 50 meter depth intervals (ALVIN dives 779, 784 and 785).



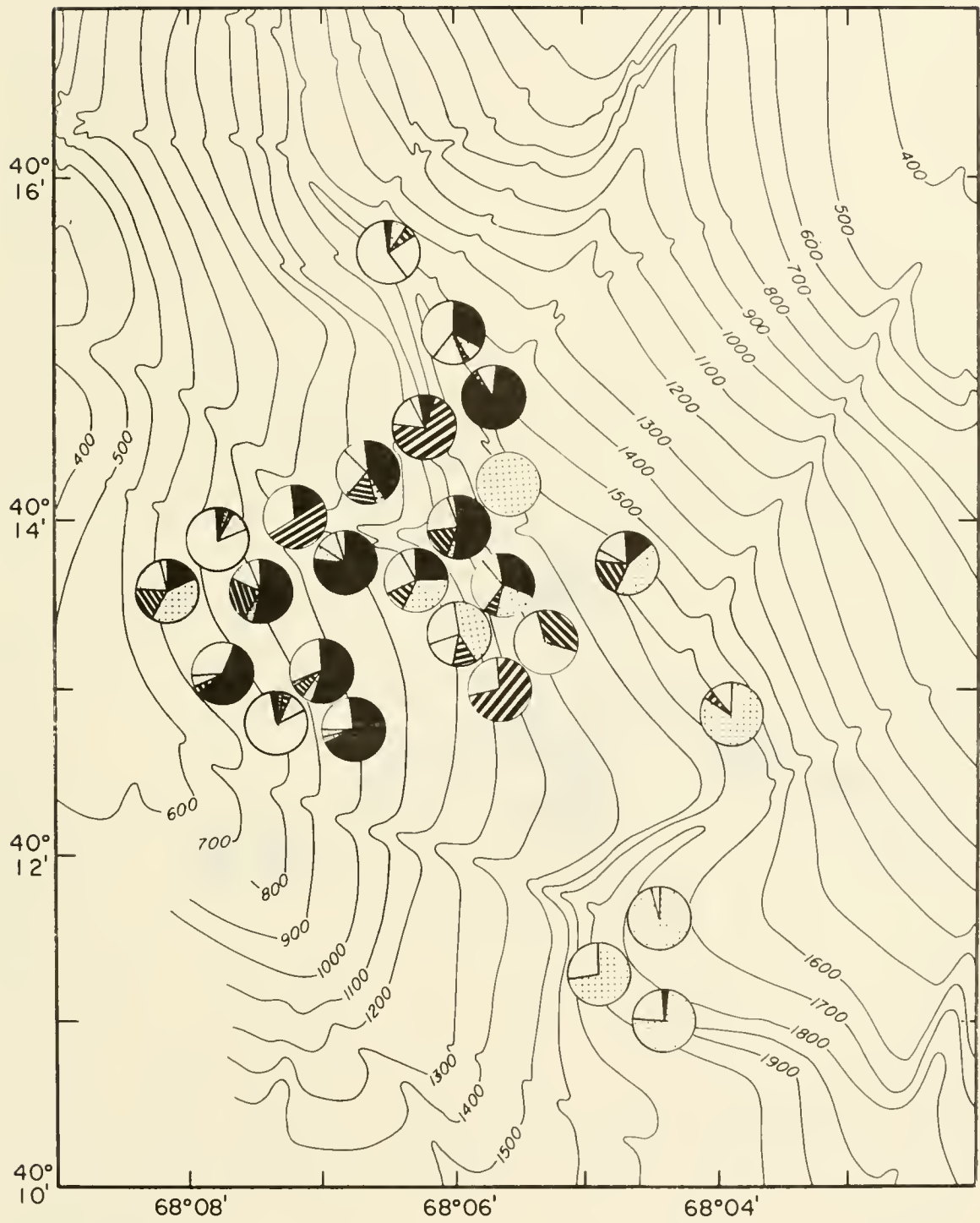
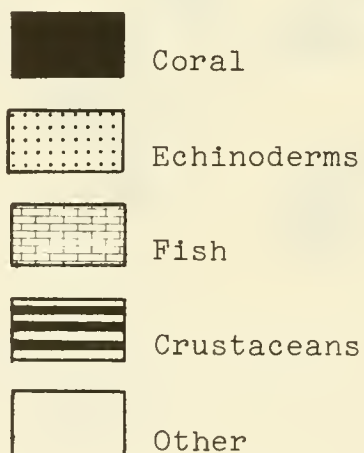


Figure C-6.

Map showing the relative percentages of major faunal groups in Heezen Canyon for 50 meter depth intervals (ALVIN dives 780, 782 and 783).



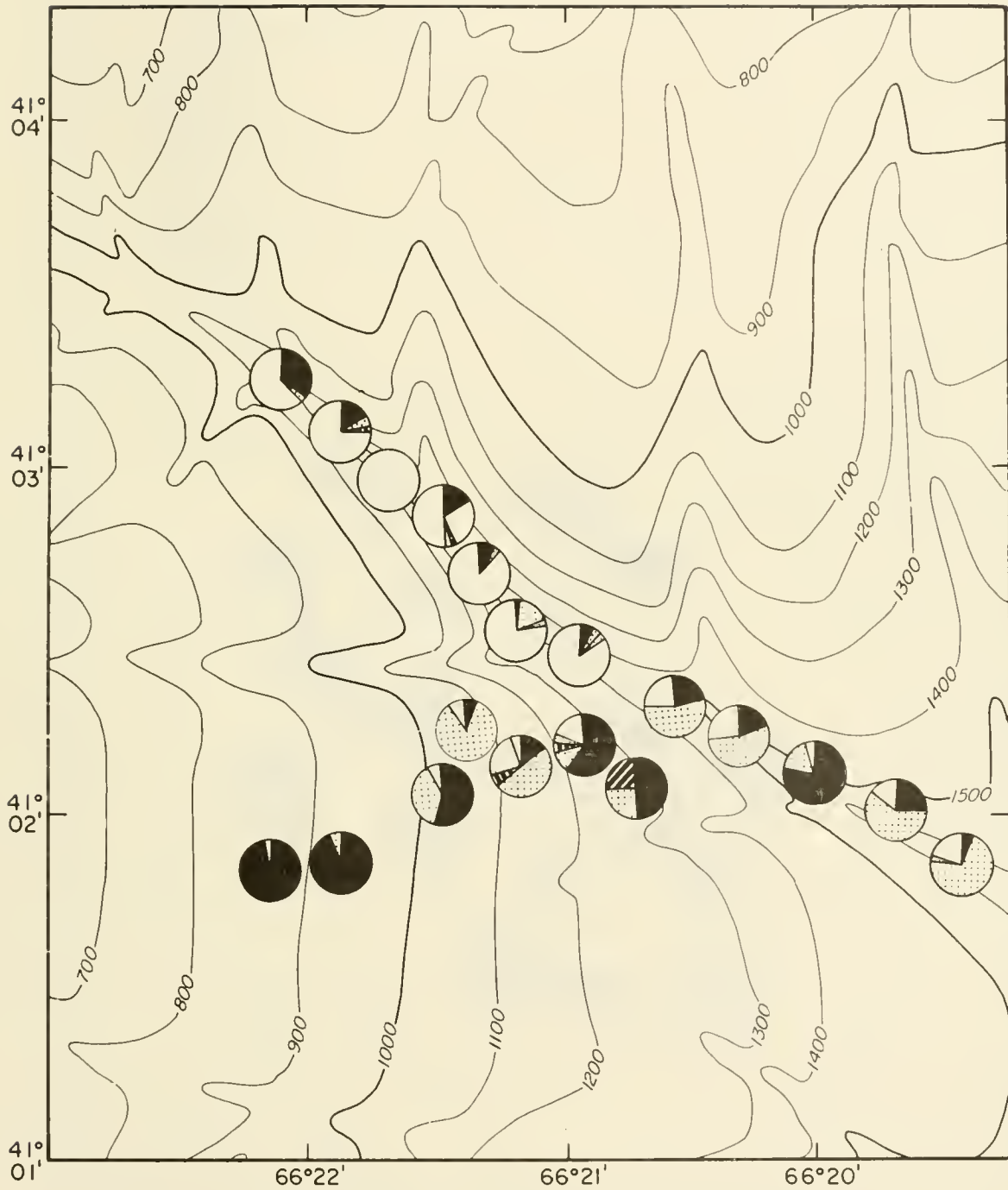
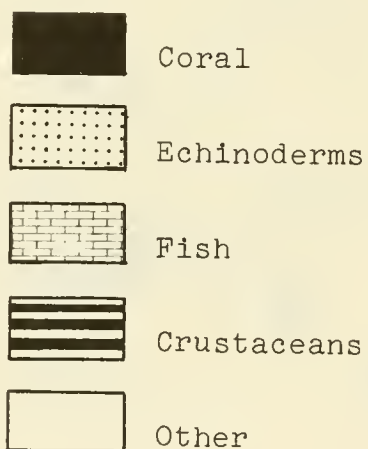


Figure C-7.

Map showing the relative percentages of major faunal groups in Corsair Canyon for 50 meter depth intervals (ALVIN dive 781).



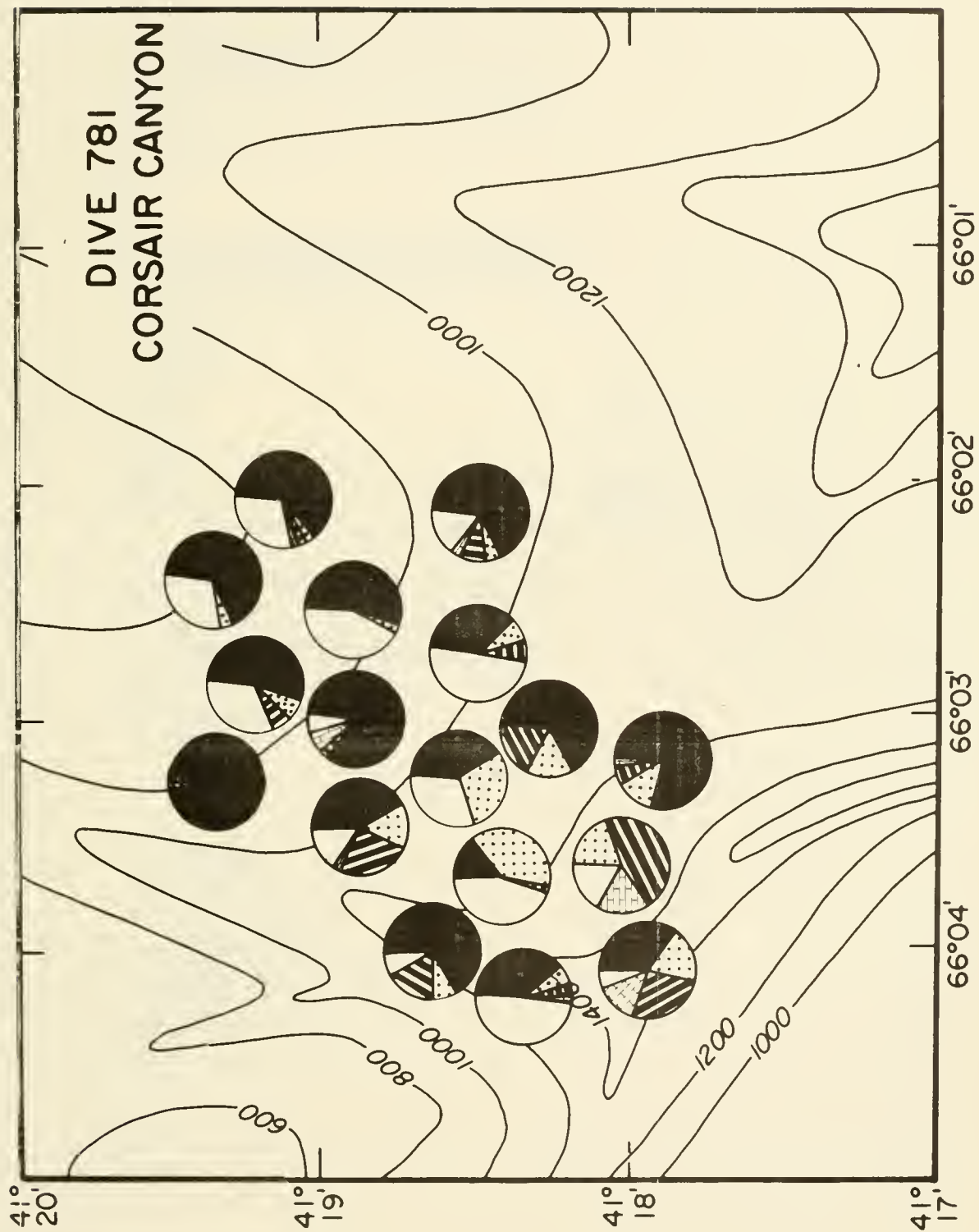


Figure D-1.

Histograms showing the depth distribution of the dominant shallow water species in number of individuals per 100m² for 50 meter depth intervals.

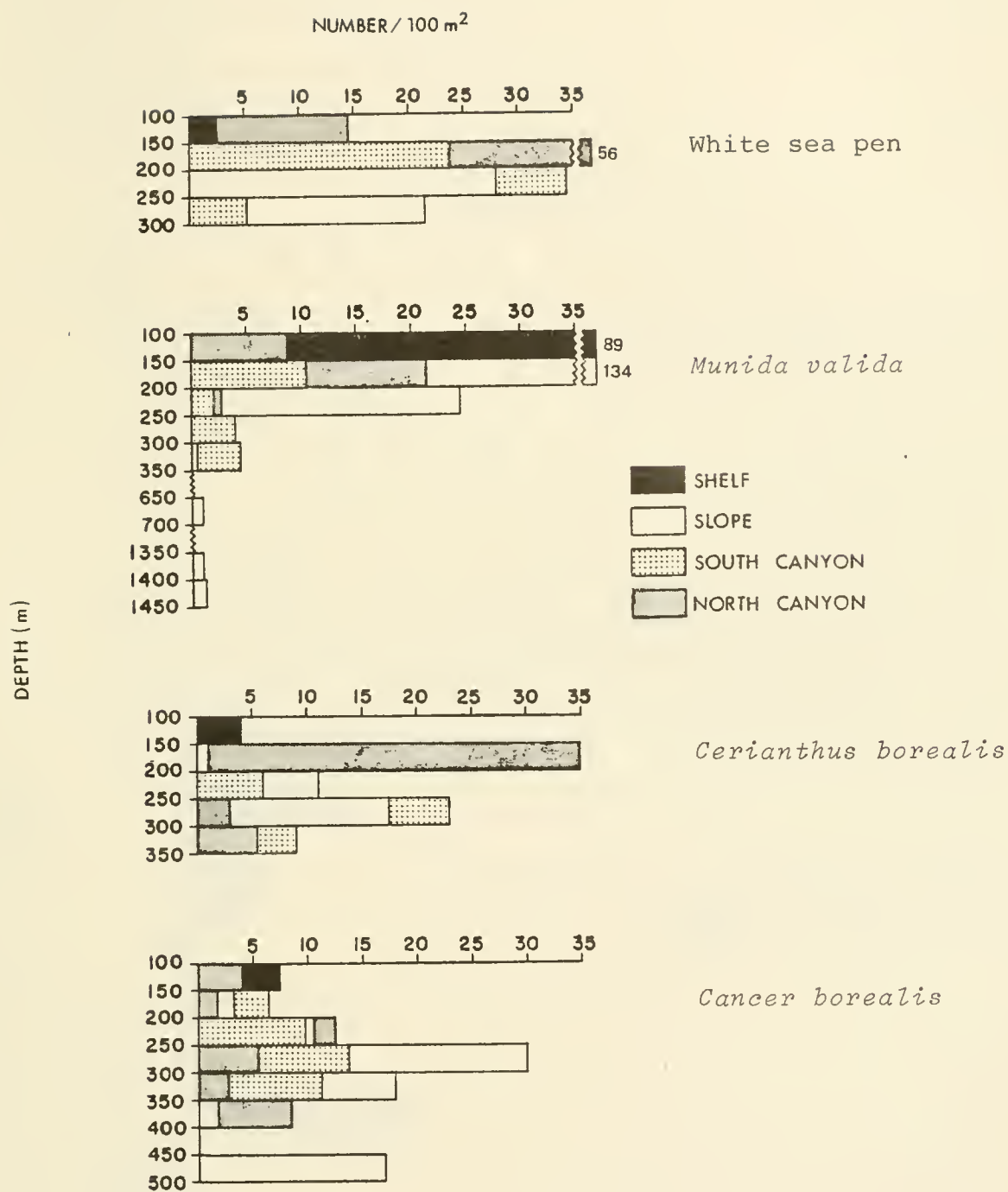


Figure D-2.

Histogram showing the depth distribution of *Cancer borealis* and *Geryon quinquedens* in number of individuals per 100m² for 50 meter depth intervals.

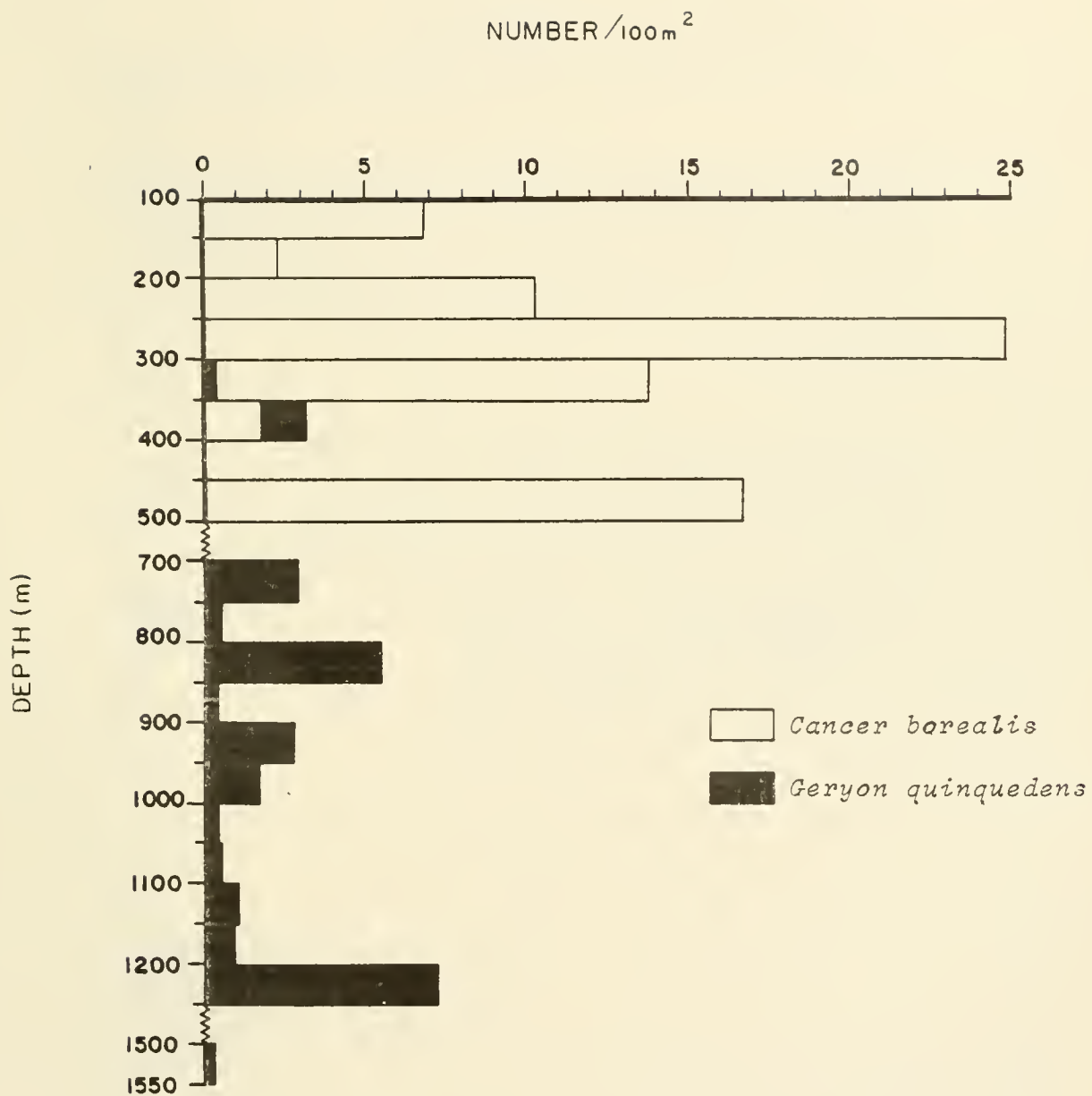


Figure D-3.

Histogram showing the depth distribution of *Anthomastus grandiflorus* and *Pennatula* sp. in number of individuals per 100m² for 50 meter depth intervals.

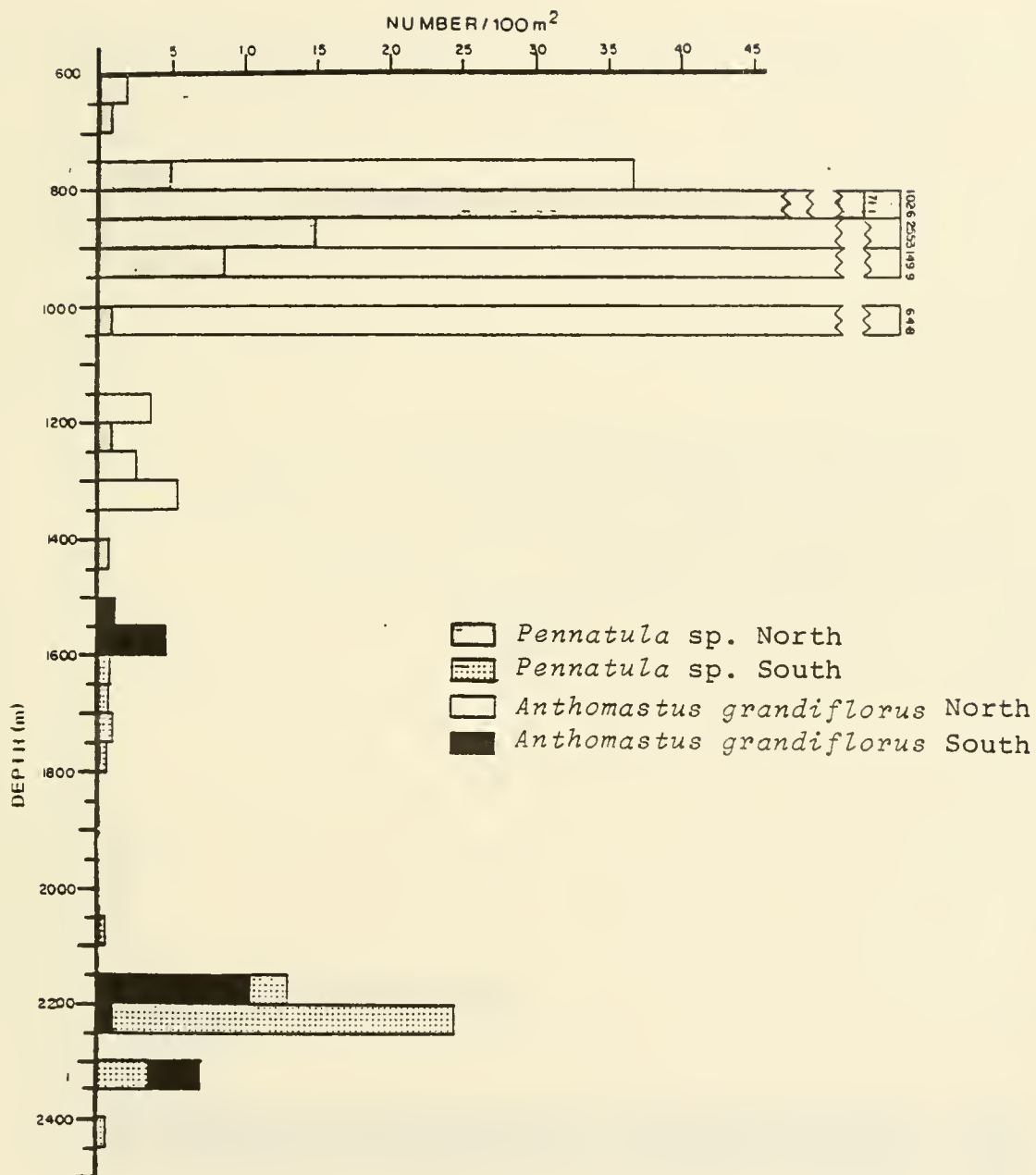


Figure D-4.

Histogram showing the depth distribution of *Acanella arbuscula* in number of individuals per 100m² for 50 meter depth intervals.

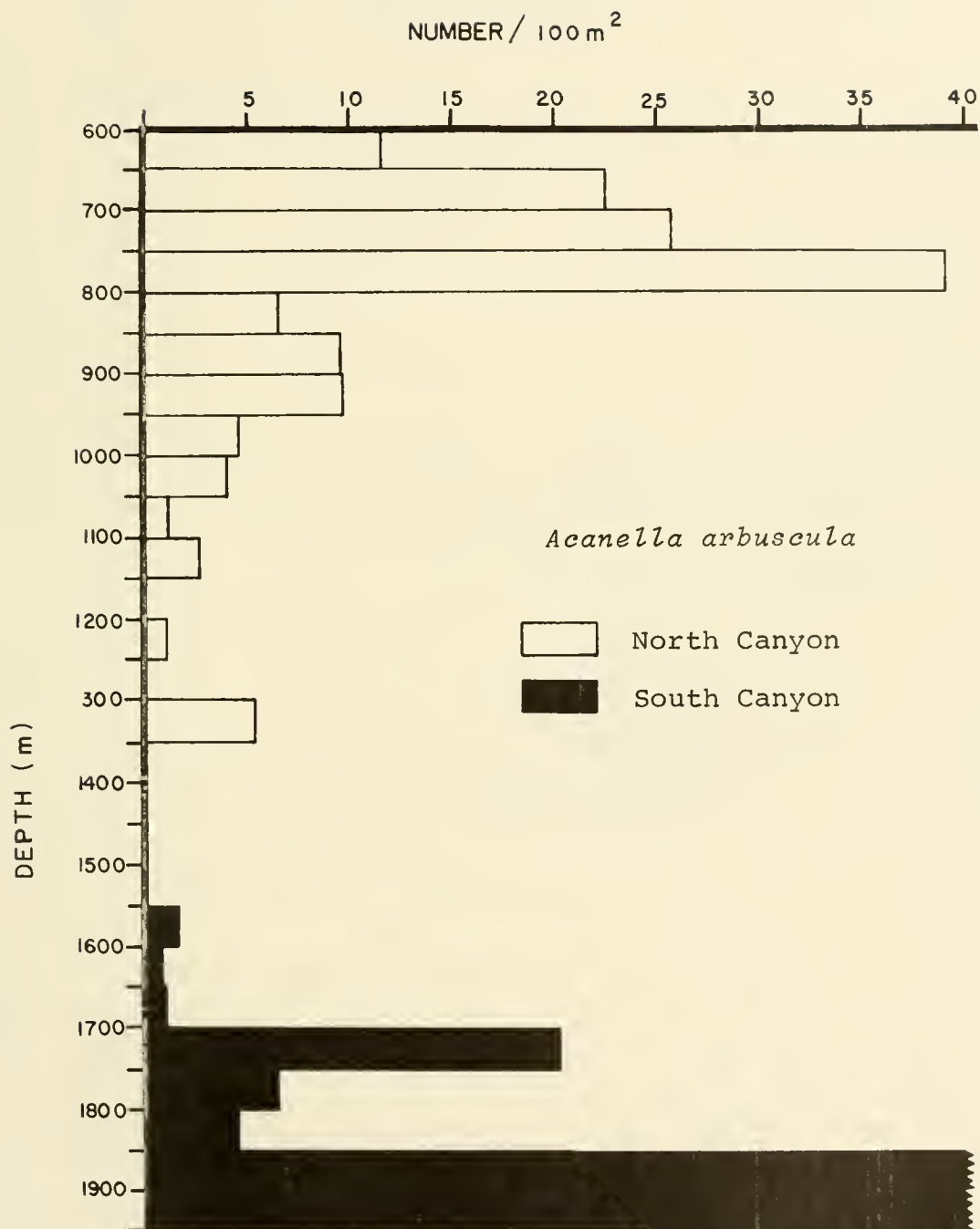


Figure E-1.

Depths at which corals and outcrops were seen
in the historical data survey with dives
arranged from south to north.

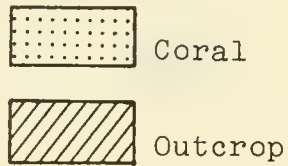




Figure E-2.

Location of the dominant coral species seen in
the historical data survey.

- *Pennatula* sp.
- ⊙ *Eunephthya* sp.
- White sea pen
- ★ *Anthomastus grandiflorus*
- ☆ *Anthomastus agassizii*
- *Acanthogorgia armata*
- *Paramuricea borealis*
- ◼ *Acanella arbuscula*
- ▲ Sea pen
- ◈ *Desmophyllum cristagalli*
- ◊ *Flabellum* sp.

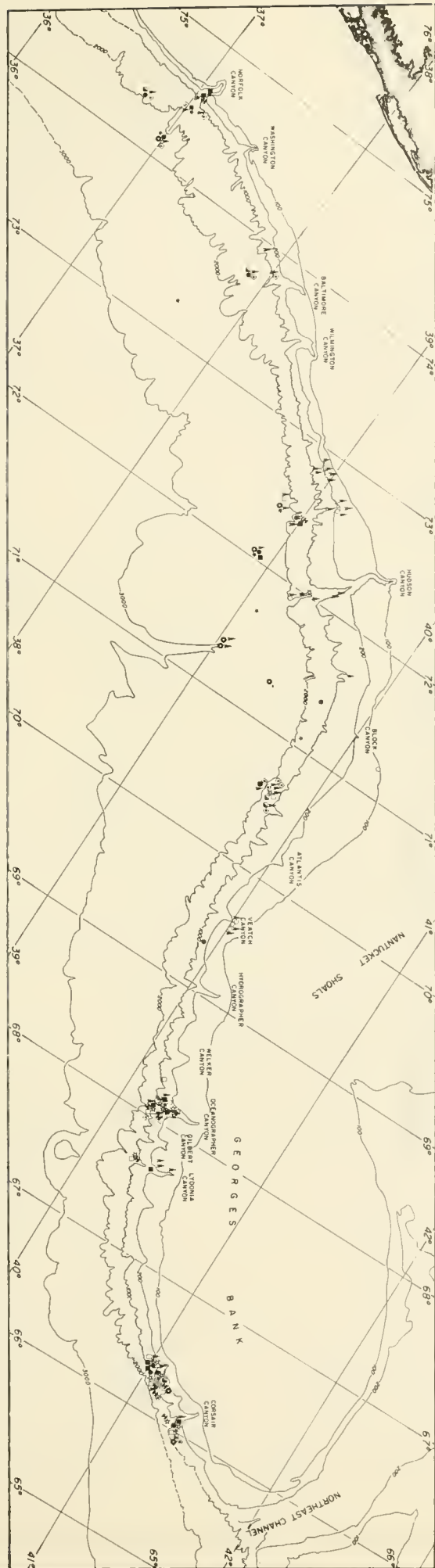
















Figure E-3.

Location of the coral species rarely seen in the historical data survey.

	<i>Umbellula lindahli</i>
	<i>Virgulina mirabilis</i>
	<i>Acanthoptilum grandiflorus</i>
	<i>Balticina finmarchica</i>
	<i>Paragorgia arborea</i>
	<i>Radicipes gracilis</i>
	<i>Chrysogorgia agassizi</i>
	<i>Lepidisis caryophylla</i>
	<i>Trachythela rudis</i>
	<i>Kophobelemnon stelliferum</i>
	<i>Dasmosmilia lymani</i>
	White feather
	Yellow gorgonian
	<i>Primnoa reseda</i>

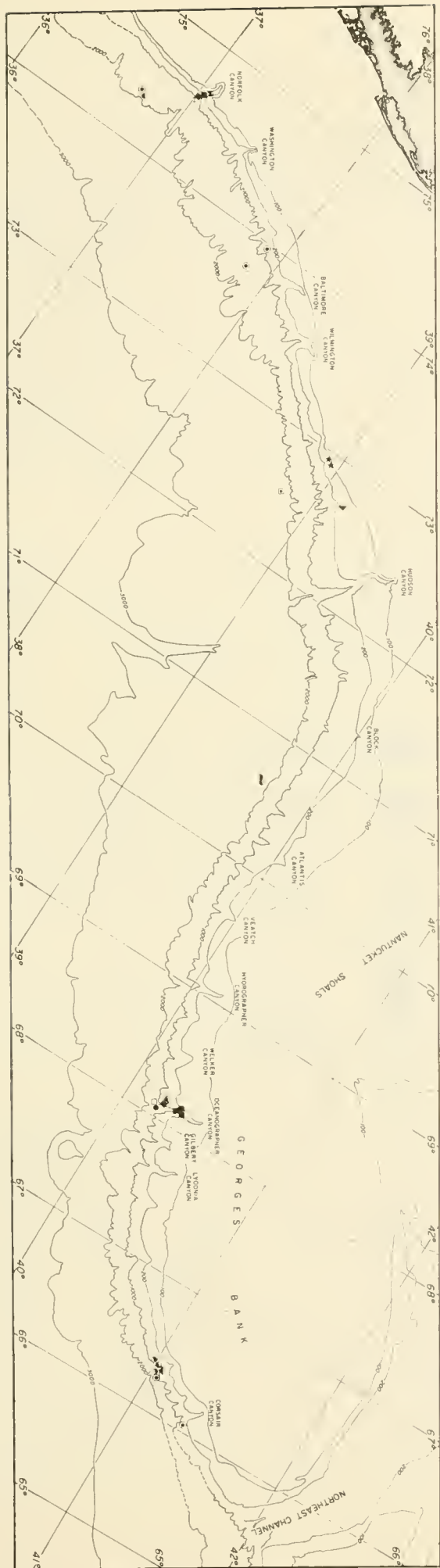


Figure E-4.

Location of coral species in Norfolk Canyon seen
in ALVIN dives 808, 809 and 810.

- *Pennatula* sp.
- ⊙ *Eunephthya fruticosa*
- ★ *Anthomastus grandiflorus*
- *Acanthogorgia armata*
- ▲ Sea pen
- ◈ *Desmophyllum cristagalli*
- ◈ *Flabellum* sp.

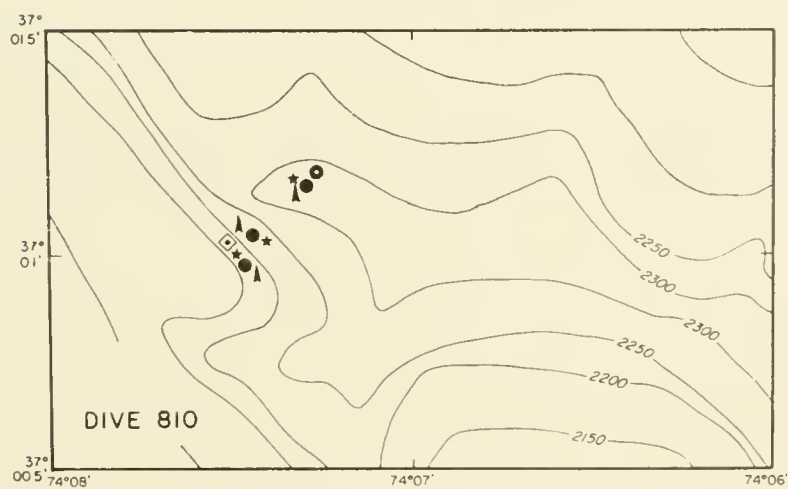
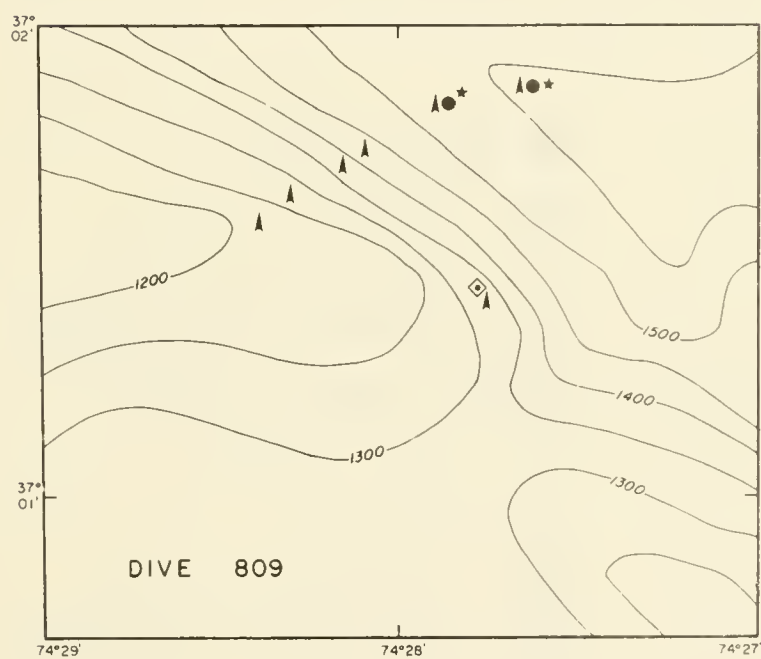
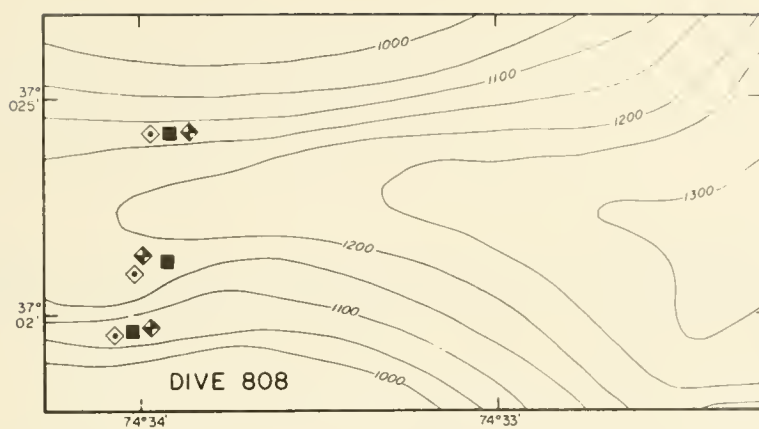


Figure E-5.

Location of coral species in Carteret and Toms
Canyons, and at DWD #106.

- *Pennatula* sp.
- ⊙ *Eunephthya fruticosa*
- ☆ *Anthomastus agassizii*
- ★ *Anthomastus grandiflorus*
- *Paramuricea borealis*
- White sea pen
- ▲ Sea pen
- *Acanthogorgia armata*
- ◩ *Desmophyllum cristagalli*
- ◪ *Flabellum* sp.

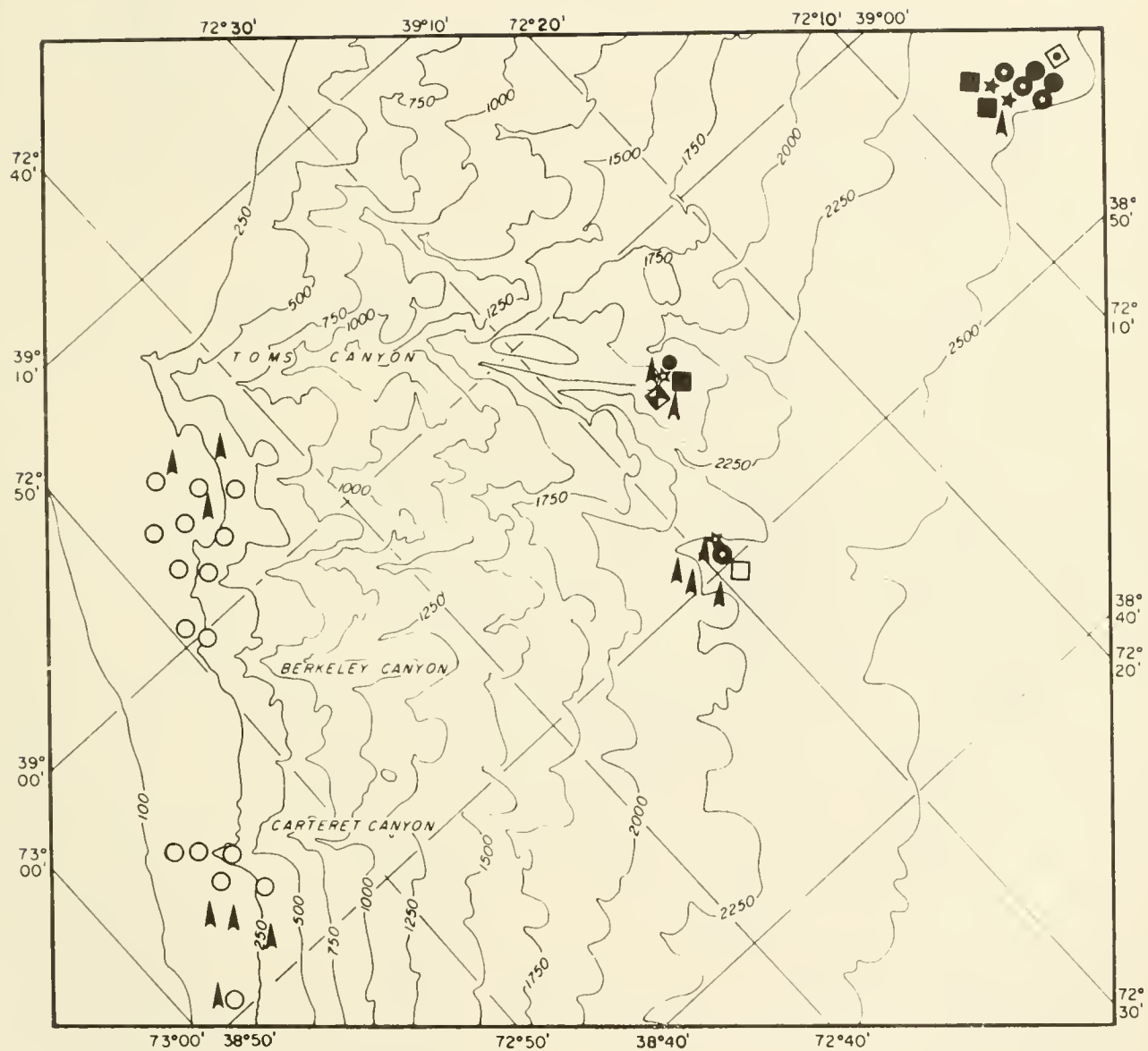
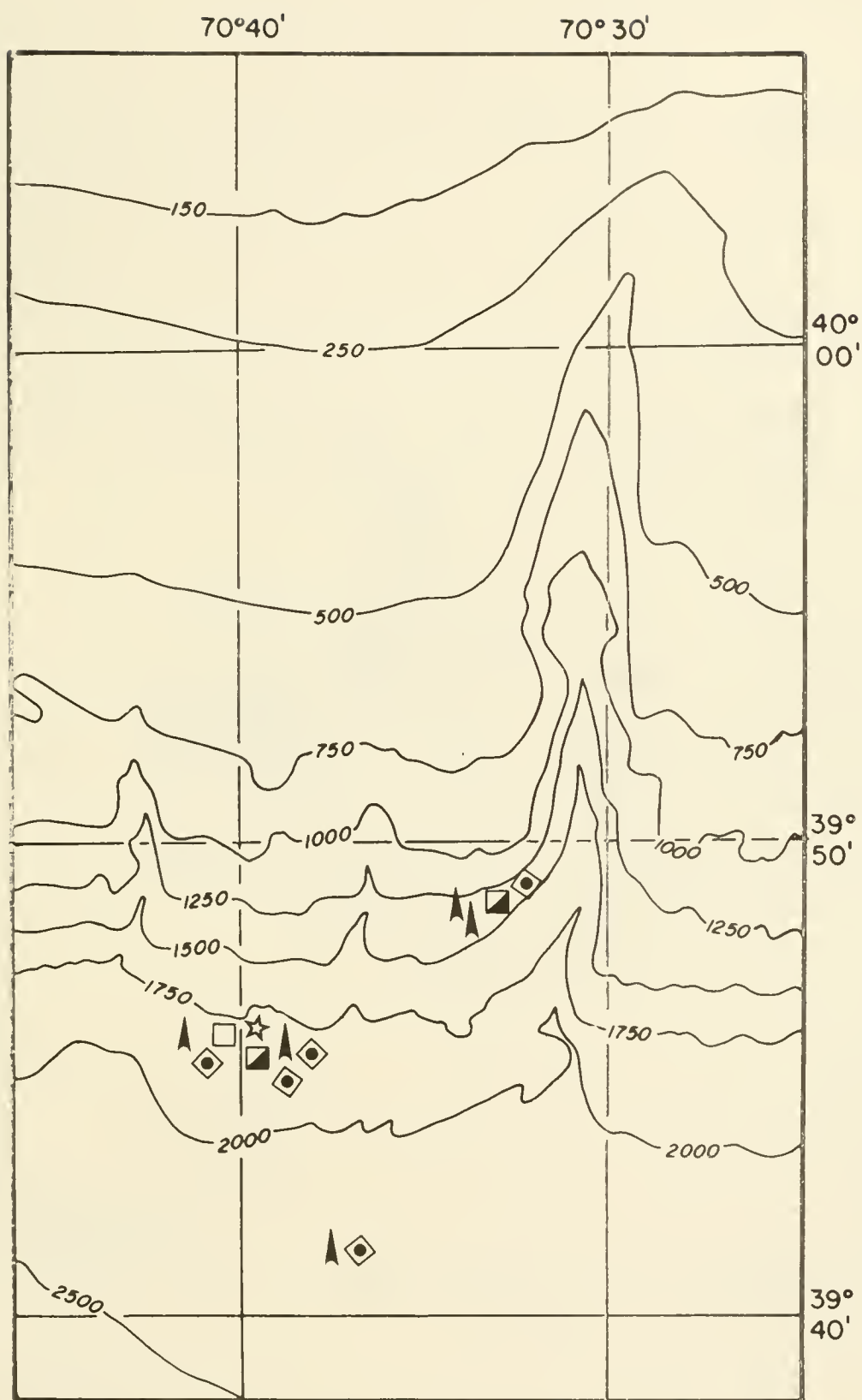


Figure E-6.

Location of coral species on the continental
slope near Alvin Canyon.

☆	<i>Anthomastus agassizii</i>
□	<i>Paramuricea borealis</i>
◼	<i>Acanella arbuscula</i>
◊	<i>Flabellum</i> sp.
▲	Sea pen



ALVIN CANYON

Figure E-7.

Location of coral species in Oceanographer Canyon
seen in ALVIN dives 779, 784 and 785.

☆	<i>Anthomastus agassizii</i>
★	<i>Anthomastus grandiflorus</i>
■	<i>Acanthogorgia armata</i>
□	<i>Paramuricea borealis</i>
◼	<i>Acanella arbuscula</i>
◈	<i>Desmophyllum cristagalli</i>
◈●	<i>Flabellum</i> sp.
▲	Sea pen

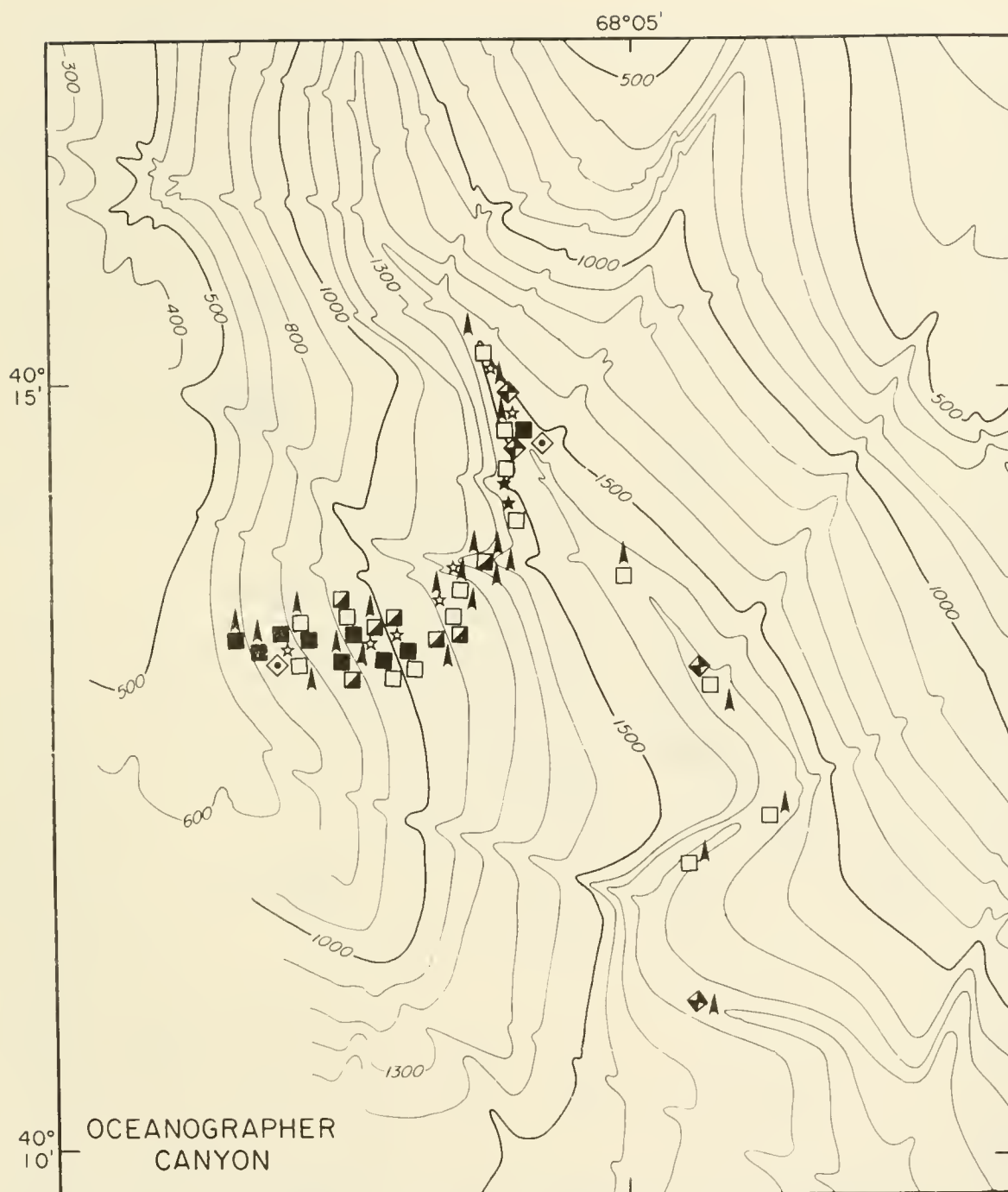


Figure E-8.

Location of coral species in Heezen Canyon seen
in ALVIN dives 780, 782 and 783.

- *Pennatula* sp.
- ☆ *Anthomastus agassizii*
- ★ *Anthomastus grandiflorus*
- *Paramuricea borealis*
- ◼ *Acanella arbuscula*
- ◈ *Desmophyllum cristagalli*
- ◈● *Flabellum* sp.
- ▲ Sea pen
- ★● *Eunepthya florida*

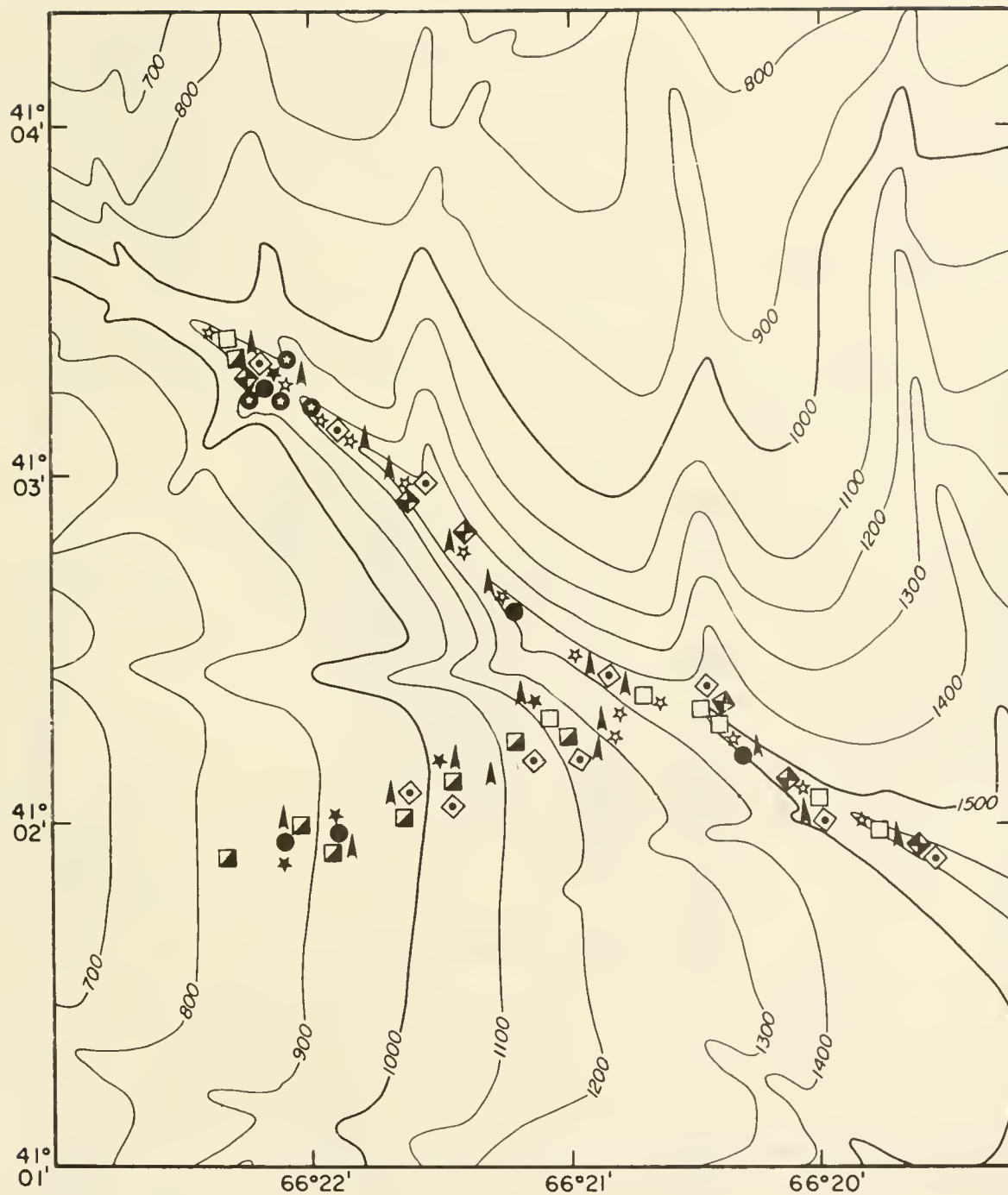


Figure E-9.

Location of coral species in Corsair Canyon seen
in ALVIN dive 781.

- *Pennatula* sp.
- ☆ *Anthomastus agassizii*
- ★ *Anthomastus grandiflorus*
- *Acanthogorgia armata*
- *Paramuricea borealis*
- ◼ *Acanella arbuscula*
- ◊ *Flabellum* sp.
- ▲ Sea pen
- ⊙ *Eunephthya florida*

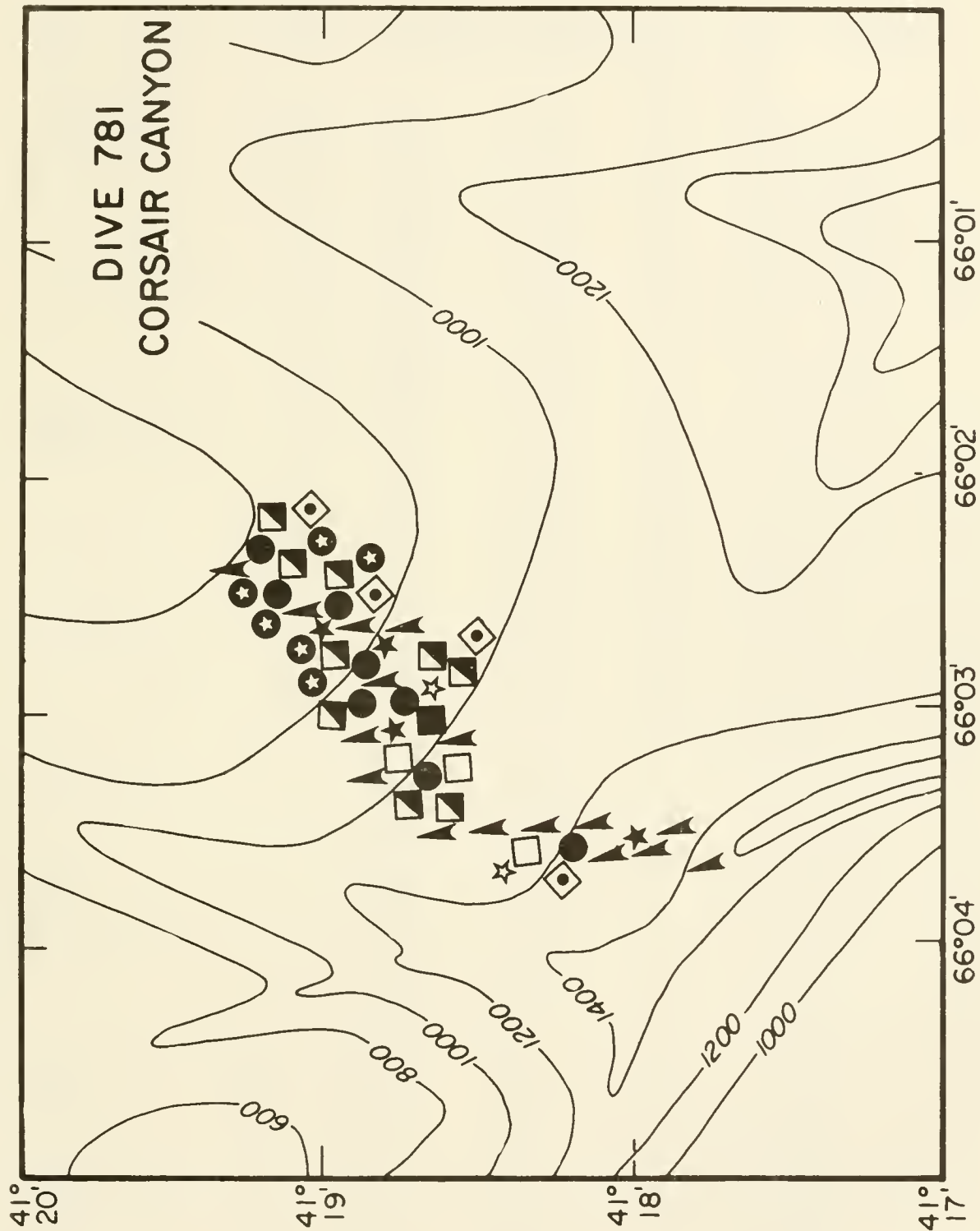


TABLE I: Dives analyzed with location and depth range. Dives 1 to 24 were Diaphus dives, the rest were ALVIN dives.

<u>AREA</u>	<u>DIVE</u>	<u>LATITUDE(N)</u>	<u>LONGITUDE(W)</u>	MIN. DEPTH (f)	MAX. DEPTH (m)	<u>REPOSITORY</u>
Corsair Canyon	781	41°18'	66°04'	630	1400	L-DGO
Heezen Canyon	783	41°03'	66°22'	1110	1400	L-DGO
	780	41°02'	66°21'	848	1519	L-DGO
	782	41°02'	66°20'	1510	1630	L-DGO
Lydonia Canyon	24	40°29.32'	67°41.32'	152	366	Slater
	20	40°25.2'	67°39.1'	170	180	Slater
	21	40°24.57'	67°42.72'	160	230	Slater
Oceanographer Canyon	784	40°15'	68°06'	1495	1572	L-DGO
	779	40°13'	68°06'	697	1560	L-DGO
	785	40°12'	68°04'	1730	1860	L-DGO
Veatch Canyon	19	40°00.65'	67°37.93'	130	180	Slater
	17	40°00.53'	69°37.48'	150	200	Slater
	18	40°00.27'	69°37.40'	150	180	Slater
Slope Near Atlantis Canyon	235	39°47'	70°32'	1265	1365	WHOI
	236	39°47'	70°32'	1330	1330	WHOI
	439	39°46'	70°40'	1755	1755	WHOI
	436	39°46'	70°40'	1805	1825	WHOI
	440	39°46'	70°40'	1795	1795	WHOI
	441	39°46'	70°40'	1745	1800	WHOI
	397	39°46'	70°41'	1820	1820	WHOI
	580	39°40'	70°37'	2165	2200	WHOI
Hudson Canyon	454	39°27.5'	72°13.1'	835	1130	Keller
	544	39°26.5'	72°11.0'	1095	1205	WHOI
	412	39°19.6'	72°02.3'	1730	1820	Keller
	592	39°10.2'	71°55.6'	1965	1985	WHOI
	593	39°01.2'	71°18.2'	2925	2925	WHOI
	594	38°51.9'	71°11.0'	2995	3165	WHOI
Tom's Canyon	6	39°03.26'	72°46.5'	155	336	Slater
	7	39°02.89'	72°45.13'	190	280	Slater
	8	39°02.33'	72°46.64'	210	310	Slater
	9	39°01.87'	72°47.55'	180	290	Slater
Slope	13	38°58.96'	72°49.32'	210	240	Slater
	14	38°57.17'	72°51.09'	210	300	Slater
Carteret Canyon	12	38°55.27'	72°54.82'	190	320	Slater
	13	38°54.67'	72°53.16'	270	330	Slater
	11	38°54.41'	72°54.44'	210	320	Slater
	3	38°50.3'	72°53.2'	135	135	Slater
	1	38°50'	72°54'	120	120	Slater
	590	38°56.5	72°26.5	1765	1833	WHOI
	591	38°54.8'	72°05.7'	2445	2507	WHOI
DWD 106	666	38°50'	72°29'	2305	2305	WHOI
	659	38°50'	72°31'	2175	2195	WHOI
	660	38°49.8'	72°31.1'	2175	2215	WHOI
Slope Near Baltimore Canyon	766	37°59.1'	73°45.2'	1550	1769	NOAA
	767	37°57.2'	73°48.5'	850	1299	NOAA
	765	37°51.9'	73°57.5'	190	459	NOAA
Norfolk Canyon	807	37°06.5'	74°27.2'	1011	1338	NOAA
	809	37°02.2'	74°27.2'	1201	1577	NOAA
	808	37°02.1'	74°33'	1052	1239	NOAA
	810	37°01.2'	74°07.5'	2160	2330	NOAA
Cape Hatteras	575	36°43.9'	74°19'	1785	1905	WHOI

TABLE II: ALVIN dives reviewed but not analyzed, due to inaccessibility of slide or poor picture quality, with location and maximum depth.

<u>AREA</u>	<u>DIVE</u>	<u>LATITUDE(N)</u>	<u>LONGITUDE(W)</u>	MAX. DEPTH <u>(m)</u>	<u>REPOSITORY</u>
Corsair Canyon	216	41°16'	66°01'	5283 ft.	WHOI
Lydonia Canyon	274	40°17'	67°40'	1660	WHOI
	275	40°25'	67°40'	590	WHOI
Oceanographer Canyon	207	40°16'	68°07'	5049 ft.	WHOI
	208	40°15'	68°06'	4923 ft.	WHOI
	835	40°21.1'	68°08.2'	690	NMFS
	836	40°17.7'	68°07.4'	1295	NMFS
	837	40°27.4'	68°07.4'	354	NMFS
	838	40°11.1'	68°04.7'	1800	NMFS
	839	40°25'	68°08.5'	516	NMFS
	840	40°28.8'	68°08.9'	946	NMFS
Slope	211	40°09'	68°17'	4010 ft.	WHOI
Slope Near Alvin Canyon	437	39°46'	70°40'	1815	WHOI
	438	39°46'	70°40'	1820	WHOI
Hudson Canyon	416	39°39.5'	72°28.0'	204	Keller
	451	39°38.5'	72°26.4'	307	Keller
	409	39°34.5'	72°25'	409	Keller
	413	39°34.5'	72°25'	481	Keller
	450	39°34.5'	72°25'	510	Keller
	455	39°32.4'	72°24.5'	570	Keller
Hudson Canyon	410	39°31'	72°21'	688	Keller
	414	39°29.5'	72°18'	844	Keller
	415	39°25.0'	72°09.5'	1439	Keller
	595	38°46.4'	71°09.8'	3264	WHOI
DWD-106	587	38°50'	72°33.9'	2148	WHOI
	665	39°49.7'	72°31.1'	2200	WHOI
Washington Canyon	811	37°22.5'	74°25'	1041	NOAA
Norfolk Canyon	574	37°03.3'	74°38.4'	656	WHOI

TABLE III: Camera lowerings reviewed with location and maximum depth.

<u>AREA</u>	<u>DIVE</u>	<u>LATITUDE(N)</u>	<u>LONGITUDE(W)</u>	MAX. DEPTH (m)	<u>REPOSITORY</u>
Shelf	Bear 281	40°12'	71°13.5'	295 ft.	WHOI
Hydrographer Canyon	A-260	40°06'	69°01'	400 fms	WHOI
Slope	A-260	39°56'	69°22'	400 fms	WHOI
	RC19/7	39°52'	71°39'	308	L-DGO
	V22/162	39°52'	69°35'	1331	L-DGO
	RC19/16	39°44'	71°41'	833	L-DGO
	Yama 3	39°42'	71°04'	1055 fms	WHOI
	RC19/6	39°41'	71°31'	1384	L-DGO
	V18/312	39°40'	69°55'	2006	L-DGO
Hudson Canyon	RC19/13	39°36'	72°25'	367	L-DGO
	RC19/12	39°30'	72°21'	663	L-DGO
	V21/139	39°30'	72°18'	774	L-DGO
	V31/101	39°30'	72°18'	833	L-DGO
	V32/5	39°30'	72°16'	608	L-DGO
Slope	V32/7	39°30'	72°05'	385	L-DGO
	RC19/5	39°23'	71°19'	2462	L-DGO
Hudson Canyon	V21/138	39°20'	72°07'	1626	L-DGO
	V32/8	39°19'	72°06'	1907	L-DGO
	RC19/4	39°17'	71°59'	1963	L-DGO
	V20/206	39°17'	71°47'	1923	L-DGO
	RC19/3	39°12'	72°02'	1274	L-DGO
Slope	RC19/18	39°09'	72°29'	516	L-DGO
Hudson Canyon	RC18/56	39°05'	71°43'	2448	L-DGO
	RC19/17	39°05'	71°42'	2262	L-DGO
Slope	RC19/2	39°01'	71°51'	2285	L-DGO
Hendrickson	RC19/11	39°01'	72°26'	1421	L-DGO
Carteret Canyon	V32/1	39°00'	72°46'	531	L-DGO
Slope	RC19/1	38°33'	71°40'	2785	L-DGO
	RC11/195	38°19.5'	70°59'	3181	L-DGO
	RC18/55	37°56'	72°37'	2854	L-DGO
	RC19/31	37°37'	73°17'	2597	L-DGO
	RC10/138	37°21'	72°13'	3492	L-DGO
	RC10/137	37°02'	72°30'	3162	L-DGO

Table IV: First ten end-members of the total fauna (excluding fish and sea pens) and the percent of sample variance explained by them.

Factor	Species	Variance	Cummulative Variance
1	<i>Ophiomusium lymani</i>	17.05	17.05
2	Shrimp	8.39	25.44
3	<i>Hyalinoecia artifex</i>	9.38	34.82
4	<i>Cerianthus borealis</i> <i>Cancer borealis</i> <i>Munida valida</i>	5.05	39.87
5	<i>Geryon quinquedens</i> Flounder	5.81	45.68
6	<i>Anthomastus grandiflorus</i> <i>Pennatula</i> sp.	4.68	50.36
7	Cerianthid anemone <i>Echinus affinis</i>	5.40	55.76
8	<i>Distichoptilum gracile</i> <i>Acanella arbuscula</i>	4.35	60.11
9	White sea pen	4.76	64.87
10	<i>Phormosoma placenta</i>	3.51	68.38

Table VI: The first ten end-members of a rotated principal components analysis of the corals in the study area.

Factor	Species	Variance	Cummulative Variance
1	<i>Distichoptilum gracile</i>	18.94	18.94
2	White sea pen	12.12	31.06
3	<i>Acanella arbuscula</i>	10.74	41.80
4	<i>Anthomastus agassizii</i> <i>Paramuricea borealis</i>	9.62	51.42
5	<i>Flabellum</i> sp.	9.20	60.63
6	<i>Anthomastus grandiflorus</i> <i>Pennatula</i> sp.	7.02	67.64
7	Whip	6.27	73.91
8	<i>Acanthogorgia armata</i>	6.50	80.41
9	<i>Desmophyllum cristagalli</i>	3.80	84.21
10	<i>Eunephthya fruticosa</i> <i>Pennatula</i> sp.	2.11	86.32

TABLE VII.

Results of rotated principal components analysis of corals listed against depth arranged from south to north. Numbers denote primary assemblages found in the dive at that depth.

[illegible]

APPENDIX I

Data sheets used for collection of data
during the historical survey.

USERS GUIDE FOR DATA INPUT SHEET A

The following is a description of the data input categories for the basic dive identification data sheet. Verbal information is recorded in numerical code form in order to ease computer handling and interfacing with analytical and interpretive programs. All numerical codes are listed on the data input sheet.

Note: This information need be recorded only once for each dive. All input is right rectified in the spaces provided unless otherwise noted.

1. Dive number: Use the number given the dive by the submersible group sponsoring the dive. Four digits are allowed.
2. Latitude: Six digits are allowed. Minutes are reported to one decimal place if possible. The decimal point must be recorded (i.e. $67^{\circ}55.4 = 6755.4$)
3. Longitude: Seven digits are allowed. Record as for latitude.
4. Date: This refers to the data of the dive. Six digits are allowed. Use zeros to fill spaces. (i.e. December 7, 1971 = 120771).
5. General area: This is the area of the dive being studied. The code list gives the two digit numeric code for most of the major features in the study area. Any other verbal location information may be added to the list and codified as it is needed.
6. Photo archive: This category indicates where the slides or film is kept. This information is given a one digit numeric code which is listed on the data input sheet.
7. Photo record: This category indicates the type of photo record available (i.e. color slide, B/W, etc.) This information is codified into one digit numbers in the code listing.
8. Submersible: This is a one digit number indicating the submersible used for the photo transect. The numeric codes are listed on the data sheet.
9. Observer: This indicates the person collecting data from the photographs. Two digits are allowed, one for each observer. The observer codes are listed on the data sheet.

DATA SHEET A

A2.

IDENTIFICATION DATA - record once per dive

DIVE NUMBER

LATITUDE

LONGITUDE

DATE

GENERAL AREA

PHOTO ARCHIVE

PHOTO RECORD

OBSERVER(s)

AREA CODES

Alvin Canyon	--01
Atlantis Canyon	--02
Baltimore Canyon	--03
Georges Bank	--04
Hatteras Canyon	--05
Heezen Canyon	--06
Hudson Canyon	--07
Lydonia Canyon	--08
Norfolk Canyon	--09
Oceanographer Canyon	--10
Veatch Canyon	--11
Washington Canyon	--12
Wilmington Canyon	--13
Continental Slope	--14
Dump Site	--15

PHOTO RECORD CODES

Color Slide	--1
Color Film Strip	--2
B/W Film Strip	--3
Hand Held	--4

OBSERVER CODES

Hecker	--1
Blechschiidt	--2
Gibson	--3
Woodroffe	--4

PHOTO ARCHIVE CODES

LDGO	--1
EPA	--2
WHOI	--3
NMFS	--4
NOAA	--5
Colorado	--6

USERS GUIDE FOR DATA INPUT SHEET B

The following is a description of the data input categories for the historical coral data. Verbal information is recorded in numerical code form as for Data Sheet A. All numerical codes are listed in Code Table B.

Note: This information must be recorded for each photograph examined. All input is right rectified in the spaces provided unless otherwise noted. Abundance data should be recorded using a red pen to allow easy reading of the data sheet.

1. Dive number: Same as for data sheet A.
2. Photo number: This is a sequential number of the slide or photograph starting with 001 for the first photograph of the dive. Three digits are allowed for this identification.
3. Depth: Depth in meters at the site of the photograph. If only one depth value is recorded in the dive record use this value.
4. Area: The area of the bottom represented in the photograph - or the area which has been counted. This is recorded in meters squared with respect to the Canadian Grid. If the Canadian Grid is not applicable (i.e. on a steep slope or outcrop) approximate the area being counted. Two digits are allowed for this value.
5. Substrate: This represents the general character of the substrate. Substrate types are codified on the attached Code Table B. Two digits are allowed for this category.
6. Comments A and B: These are general comments about the substrate, biota, etc. Two comments categories are allowed here (Comments A and Comments B) for flexibility. (i.e. if both ripple marks and biotic associations are noted in one photograph they may both be recorded). This verbal information is codified in Code Table B with two digits for each comment. This single code listing is used for both Comments A and Comments B categories.
7. Same: This category is checked if the photograph is the same as previous photographs. In such cases, only the dive number and slide number need be recorded. This check will automatically tell the keypuncher to duplicate the previous data card.
8. Taxa: The most commonly found taxa are listed on the data sheet. Each taxon is assigned a three digit code number. Two digits are allowed next to each code number for abundance data. If no specimens of a particular taxon are found no record need be made. Open spaces are available on the right hand side of the data sheet for rarer taxa. These are listed with their assigned code number in Code Table B. Only those taxa which are present in a photograph need be recorded or listed. If taxa are found which are not listed in the code table, they may be added to the listing and given a three digit code number. These code numbers should be unique and sequential in order to avoid confusion.

CODE TABLE B

Substrate codes

Mud	01
Sand	02
Gravel	03
Cobbles	04
Boulders	05
Outcrop	06
Consolidated	
clay	10
Talus	11

Comment codes

Ripples	01
Scour	02
Overhang	03
Associations	04
Dead ?	05
Tracks	06
Garbage	07
Coral rubble	08
Shell hash	09

COMMON TAXA

Urchin	001	<i>Colossendeis colossea</i>	032
<i>Echinus affinis</i>	002		
<i>Echinus alexandri</i>	003	Alcyonarian	033
<i>Hygrosoma petersi</i>	004	<i>Anthomastus agassizii</i>	035
<i>Phormosoma placenta</i>	005	<i>Anthomastus grandiflorus</i>	036
		<i>Pennatula</i> sp.	038
Ophiuroid	006	<i>Paramuricea borealis</i>	039
<i>Ophiomusium lymani</i>	007	<i>Eunephthya fruticosa</i>	040
<i>Amphilimna olivacea</i>	008	<i>Acanella arbuscula</i>	050
<i>Ophiocantha</i> sp.	009		
		Scleractinian	042
Asteroid	010	<i>Desmophyllum cristagalli</i>	043
<i>Astropecten americanus</i>	011	<i>Flabellum alabastrum</i>	044
<i>Porcellanaster caeruleus</i>	012	<i>Lophelia prolifera</i>	045
<i>Euphronides</i> sp.	014	"Sea pens"	047
<i>Paeleopatides</i> sp.	015	"Golf balls"	048
		Fish	049
<i>Lithodes agassizi</i>	017	Burrows	051
<i>Cancer borealis</i>	018		
<i>Geryon quinquedens</i>	019		
<i>Munida valida</i>	020		
<i>Parapagurus</i> sp.	021		
Polychaete	022		
<i>Hyalinoecia artifex</i>	023		
Sponge	024		
<i>Hyalonema</i> sp.	025		
Anemone	027		
<i>Cerianthidae</i>	028		
<i>Actinauge longicornis</i>	029		
<i>Actinoscyphia saginata</i>	030		

SELDOM SEEN SPECIES

Ophiuroid	006	<i>Distichoptilum gracile</i>	087
<i>Ophiomusium armigerum</i>	052	<i>Virgularia mirabilis</i>	089
<i>Asteronyx loveni</i>	054	<i>Anthoptilum grandiflorum</i>	090
<i>Ophianax</i> sp.	128	<i>Balticina finmarchica</i>	091
		<i>Acanthogorgia armata</i>	114
Asteroid	010	<i>Trachythela rudis</i>	129
<i>Freyella</i> sp. A	056	<i>Eunephthya florida</i>	133
<i>Freyella</i> sp. B	057	Whip	104
<i>Solaster benedicti</i>	059	Pink column	117
<i>Dytaster grandis</i>	060	Yellow gorgonian	127
<i>Plutonaster intermedius</i>	061	White sea pen	132
<i>Pseudoarchaster pareli</i>	062		
<i>Porania</i> sp.	063	Scleractinian	042
<i>Zoroaster fulgens</i>	123	<i>Dasmosmilia lymani</i>	096
<i>Henricia</i>	131	<i>Flabellum angularis</i>	099
Stalked crinoid	119		
		Octopus	102
Holothurian	013	Squid	103
<i>Mesothuria lactea</i>	064	Flounder	105
<i>Peniagone</i> sp.	116	Skate	107
Lemon cucumber	124	Ray	115
Anemone	027	Stalked thing	109
<i>Bolocera tuediae</i>	066	White hydroid	111
<i>Cerianthus borealis</i>	112	Crowned polychaete	120
Anemone A	068	Gastropod	121
Anemone B	069		
Anemone C	070	<i>Brissopsis</i> sp.	125
Anemone D	106		
Crustacean	016		
<i>Acanthocarpus alexandri</i>	071		
<i>Homarus americanus</i>	072		
<i>Munidopsis rostrata</i>	073		
<i>Bathynectes superba</i>	110		
Pink galatheid crab	122		
Pink shrimp-like crab	130		
Shrimp	113		
Sponge	024		
Lettuce sponge	076		
White feather	126		
Alcyonarian	033		
<i>Lepidisis caryophyllia</i>	077		
<i>Chrysogorgia agassizii</i>	082		
<i>Radicipes gracilis</i>	083		
<i>Kophobelemnion stelliferum</i>	118		

APPENDIX B

Taxonomic Description of Some Deep-Sea
Octocorals of the Mid and North Atlantic

by

Dennis M. Opresko

OCTOCORALLIA

(=Alcyonaria)

Octocorals are colonial anthozoan coelenterates. They differ from other coelenterates in that their polyps have an octamerous biradial symmetry, and (with a few exceptions) their coenenchymal tissue contains minute calcareous structural elements called spicules. Unless secondarily modified, the polyps typically have eight pinnately branched tentacles, eight complete septa with septal filaments, and one siphonoglyph. Such polyps are termed autozooids. In some species there is also a second type of polyp called a siphonozooid. Siphonozooids are smaller than autozooids, they have only a single pair of septal filaments, and their tentacles are greatly reduced in size or absent. Species with both polyp forms are said to be dimorphic.

Octocoral polyps vary in appearance depending on their state of contraction or retraction. When alive the polyps are often observed with the body and tentacles fully expanded; however, the tentacles can also be contracted and curled in over the mouth of the polyp while the body of the zooid remains extended (permanently so in some species). Furthermore, in some species the entire upper portion of each polyp (anthocodia) is retractible into the lower portion (anthostele). The anthosteles are often raised up on cylindrical, or conical wart-like prominences called calyces, which are distinguishable on the surface of the colony even when the polyps are completely retracted. The calyces are usually

heavily spiculated - sometimes with the spicules at the upper edge developed into long projecting spines. The anthocidia can also be spiculated - the spicules most frequently being arranged in eight series of vertical rows corresponding to and sometimes extending into the tentacles. There can also be a spicular collaret consisting of several transverse rows encircling the lower portion of the anthocodia. In some species with non-retractile polyps the anthocodia blends imperceptibly with the anthostele to form an elongated calycular-like structure often reinforced with eight vertical rows of spicules and augmented at the base of the tentacles with a series of projecting spines.

The size, shape, and arrangement of the spicules on the polyps as well as in other parts of the colony are diagnostic features of octocorals at the species, generic and even family level. At the ordinal and subordinal level, the octocorals are differentiated on the basis of the colonial growth form and the presence or absence of a central core which functions as an axial support for the colony. Representatives of three octocoral orders occur in deep water off the northeast U.S. coast: these are the Alcyonacea, the Gorgonacea, and the Pennatulacea. In the Alcyonacea the colonies are massive, lobate or branched, and there is no central axial core. Some of the polyp cavities extend from the top of the colony to the base. Alcyonaceans usually grow attached to hard substrates, but a few species are also found embedded in soft sediments. Alcyonaceans occurring within the study area include

two species of the genus *Anthomastus*, three species of *Eunephthya* and *Trachythela rudis*.

In the Gorgonacea the colonies typically have a central core consisting either of a calcareous or proteinaceous material (gorgonin) or a combination of both substances. In the suborder Scleraxonia the core (also called medulla) contains calcareous spicules either loosely held together or fused into a solid mass. Some species of scleraxonians grow as lobate encrusting masses outwardly similar to some alcyonaceans, but these usually also develop into upright free standing colonies. Several species are dimorphic. The two most common species of scleraxonians occurring off the northeast coast are *Paragorgia arborea* and *Anthothela grandiflora*.

In the second suborder of gorgonians, the Holaxonia, the colonial axis is partially or totally composed of a proteinaceous, horn-like material called gorgonin. This material is deposited in concentric layers and has either a solid or hallow, chambered center. In genera such as *Primnoa* the axis is heavily permeated with calcium carbonate, in others (*Acanella*) it is segmented such that sections of gorgonin alternate with ones made up of solid calcium carbonate. There are no dimorphic species in this suborder. Off the northeast coast the most common species of holaxonians are *Primnoa reseda*, *Paramuricea grandis* and *Acanthogorgia armata*. Also known from this area are *Paramuricea placomus*,

Acanella arbuscula and *Chrysogorgia agassizii*.

The Pennatulaceans are highly modified octocorals. They develop from greatly enlarged primary polyps which serve as the structural foundation of the colony. The lower part of the primary polyp is modified into a stalk which anchors the colony in soft substrates. On its upper part, which is called the rachis, are a variable number of dimorphic secondary polyps. This arrangement of secondary polyps on the rachis is a taxonomic character used to differentiate pennatulaceans at the genus and family level. While the small siphonozooids are usually distributed irregularly on the rachis, the autozooids are often placed in a symmetrical radial or bilateral pattern. Although all seapens are unbranched, in the family Pennatulidae there is a series of long narrow extensions of the rachis extending out on either side (containing autozooids) and giving the colony the appearance of being pinnately branched. Two species of this family (genus *Pennatula*) occur in deep water off the northeast coast along with single species of the genera *Balticina*, *Kophobelemnon*, *Anthoptilum*, *Distichoptilum* and *Stylatula*.

ALCYONACEANS

Anthomastus grandiflorus (Verrill)

Anthomastus grandiflorus, Verrill, 1878b:376; 1883:41; 1922:40
Anthomastus grandiflorus, Deichmann, 1936:52

Species of the genus *Anthomastus* form mushroom-shaped colonies consisting of a cylindrical polypless stalk and an upper, dome-shaped polyp-disk. The disk bears two types of polyps; large autozooids (3-4 cm long) and minute siphonozooids. In *A. grandiflorus* the autozooids are often confined to the margin of the disc and the siphonozooids are scattered over the entire surface giving it a granular texture due to their slightly raised calyces. The autozooids are completely retractile; however, they are often preserved in a partially or totally expanded state. The spicules are long, sparsely warted spindles (0.3 mm long) or short, roughly-warted, stellate or capitate rods. In this species the lower end of the stalk has lobe-like swellings which anchor the colony in soft substrates. Living colonies are bright red or purple - the color fading only slightly after preservation. The species is known from the eastern Atlantic and in the west from Newfoundland south into the Caribbean. Its depth range is 250 to about 600 fm.

In the historical survey *A. grandiflorus* was found from Corsair Canyon to Norfolk Canyon between the depths of 750 to 2600 m. Exceptionally high concentrations of this species were seen during a dive on the west wall of Heezen Canyon. *A. grandiflorus* frequently co-occurred with a species of *Pennatulula*. In the field study two individuals of *A. grandiflorus* were found at 868 m in Baltimore Canyon and one individual was found at 826 m in Oceanographer Canyon.

Anthomastus agassizii (Verrill)

Anthomastus agassizii, Verrill, 1922:40
Anthomastus agassizii, Deichmann, 1936:54

This species is similar in appearance to *A. grandiflorus*. In his original description Verrill differentiated the two species on the basis of differences in the size of the polyps (smaller in *agassizii*) and in the size and shape of the spicules (longer and more spinulose spindles and more strongly warted stellate forms). Deichmann further defined the species to include only attached colonies (stalk ending in adhesive disk rather than a multilobed anchor) in which the autozooids are scattered across the entire disc and not confined to the margin. *A. agassizii* is also bright red in color and its bathymetric and geographic distribution overlap that of *A. grandiflorus*. It has been reported from George's Bank to the Lesser Antilles at depths of 200 to 1030 fm.

In the historical survey this species was found from Corsair Canyon to Hudson Canyon between the depths of 750 to 1900 m. Highest concentrations were observed in the axes of Oceanographer and Heezen Canyons. In the field study only several individuals of *A. agassizii* were found. They occurred between 1057 to 1326 m in Oceanographer Canyon.

Eunephthya glomerata (Verrill)

Eunephthya glomerata, Verrill, 1869:284
Alcyonium lutkeni, Verrill, 1879:200
Eunephthya lutkeni, Verrill, 1883:43
Drifa glomerata, Verrill, 1922:31
Eunephthya thyrsoides, Verrill, 1922:29
Eunephthya glomerata, Deichmann, 1936:261

The three common species of eunephthids occurring in deep water off the northeast coast all form fleshy arborescent colonies consisting of a polypless stalk and a branched floral-like upper section. The branches are thick, relatively short, and cone-shaped with a very broad base. The species differ in terms of spiculation, and in the density and distribution of the polyps. In *Eunephthya glomerata*, the stalk is very short, and the branches, except for near the base, are crowded on all sides with numerous clusters of 3-12 polyps. The polyps are 4.5 mm long when expanded, but only 1-3 mm when contracted. They are not completely retractile and are generally curved upward toward the distal end of the branches. Each polyp, with its constricted base and swollen upper end, gives the appearance of being stalked. The surface of the polyps and coenenchyme is stiff and rough due to the presence of numerous strongly spinulose spicules. The spicules are warted spindles of various sizes. On the outer side of the polyps (particularly along rib-like striations) the spicules are club-shaped with the tubercles becoming enlarged at one end. Unlike the case in *E. fruticosa* but similar to that for *E. florida*, the polyp-spicules are nowhere grouped together into transverse rows extending around the polyp body. In life the colonies are pale pink or red, brown on the stalk and becoming translucent and sometimes yellowish or orange when expanded. Preserved colonies are grey. The species occurs in the northeast Atlantic and in the northwest as far south as New England. It has been found at depths of 52 to 600 fm.

Several individuals of an alcyonarian resembling *E. glomerata* particularly with regard to density of polyps, were found during the field study at 200 m and 562 m depth in Lydonia Canyon.

Eunephthya florida (Rathke)

Gorgonia florida, Rathke, 1806:137
Alcyonium multiflorum, Verrill, 1879:200
Duva multiflora, Verrill, 1922:35
Eunephthya florida, Deichmann, 1936:62

This species is similar to *Eunephthya glomerata* in that it forms fleshly arborescent colonies with largely non-retractile, club-shaped polyps. It differs from that species in that the polyps in *E. florida* are concentrated at the tips of the branches and there are no club shaped spicules. The spicules are all tuberculated spindles and capstans. In this respect the species is similar to *E. fruticosa*. It differs from the latter species in its smaller polyps (1-2 mm long), absence of rib-like ridges along the length of the stalk and branches, and absence of a colleret of spicules around the polyps. In life the colors are light red or brown. Preserved colonies are grey, yellow, or brown. It occurs on both sides of the Atlantic at depths of 88 to 649 fm. It is usually found at about 200 fm.

In the historical survey *E. florida* was found in the axis of Heezen Canyon between 1100 and 1200 m depth and on the wall of Corsair Canyon between 600 and 1000 m depth. In the field study this species was found in all three canyons, but was only found in high abundances in Lydonia Canyon. Its depth range was 350 to 1500 m. *E. florida* was the only species of *Eunephthya* recovered during the field sampling.

Eunephthya fruticosa (Sars)

Alcyonium fruticosum, Sars, 1860:140
Gersemia longiflora, Verrill, 1883:44
Gersemia fruticosa, Verrill, 1922:23
Gersemia mirabilis, Verrill, 1922:26
Gersema studeri, Verrill, 1922:48
Eunephthya fruticosa, Deichmann, 1936:64

In general appearance colonies of *E. fruticosa* are intermediate between those of *E. glomerata* and *E. florida*. The polyps are not as densely distributed on the stalk and branches as in *E. glomerata*, nor are they largely confined to the tips of the branches as in *E. florida*. They occur singly or in loose clusters of up to 5 individuals. They are retractile but are often seen in a partially or fully expanded condition. Expanded polyps can be 8 mm long (*longiflora* variety) but most are only 3 mm long. Each polyp has a well-defined calyx which has a lobed margin. Spicules occur throughout the colony as warted (tuberculated) rods and spindles, but there are no club-shaped spicules as in *E. glomerata*. In the distal or anthocodial part of the polyps the spicules are arranged in eight vertical double rows (chevron pattern), and there are also five to ten transverse rows formed into a collaret on the basal or middle portion of the polyps. The anthocodial spicules are up to 0.35 mm long while those on the stalk are usually less than half as long. In life the colonies are a translucent blue, but they turn greyish-brown or black when preserved. The species occurs on both sides of the north Atlantic. In the west it extends south to off the coast of Delaware. In polar regions it is found in shallow water, but off the U.S. coast it is usually deeper than 1000 fm.

The species was found in the historical survey from Hudson Canyon to Norfolk Canyon between the depths of 2300 and 3000m.

Trachythela rudis (Verrill)

Trachythela rudis, Verrill, 1922:37

Clavularia rudis, Deichmann, 1936:36

Although originally described as a stoloniferan, this species forms small, fleshy, multi-polyped colonies resembling small unbranched eunephthids. The colonies are generally not more than 2 cm high and about as wide. Solitary polyps, or colonies of 2-5 or more individuals, are often connected by basal encrusting membranes. The expanded polyps are up to 8 mm high and have a well defined calyx which is often outlined at the margin by sharp, projecting spines. Although the polyps are completely retractile, they are usually partially exposed - revealing a very spiculose anthocodia. Spicules in the calyces, coenenchyme and interior portions of the colonies are also very numerous. Curved or bent, sparsely warted spindles predominate in the inner tissues. The anthodial spicules, some of which are 1.25 mm long, are arranged in a transverse collaret of 4-6 rows and in vertical rows extending up the outer side of the tentacles to form an eight-rayed spiculose operculum in contracted polyps. The spicules of the calycular margin are large bent spindles, one end of which is developed into a long, acute smooth-surfaced spine. In life colonies are a deep-red in color. The species is only known from off the northeast U.S. coast at depths of several hundred fathoms.

In the historical survey this species was found on the wall of Oceanographer Canyon at 750 m. and in the axis of Heezen Canyon at 1100 m. Several individuals of *T. rudis* were recovered during the field study from approximately 900 m. depth in both Oceanographer

and Lydonia Canyons.

GORGONACEANS

Paragorgia arborea (Linnaeus)

Alcyonium arboreum, Linnaeus, 1758

Paragorgia arborea, Milne, Edwards and Haine, 1857

Paragorgia arborea, Verrill, 1922:17

Paragorgia arborea, Deichmann, 1936:81

Paragorgia arborea is the largest gorgonian found along the northeast coast. Colonies can be 1.5 m or more in height and have a basal diameter of 10 cm or more. The branches, which tend to lie in a single plane, are thick, rigid and often have nodes or swellings along their length and especially at their free end. As a scleraxonian gorgonian, *P. arborea* lacks a central axis of gorgonin and instead the central core of the stem and branches is densely packed with calcareous spicules. The spicules are in the shape of irregularly warted or tuberculated rods and spindles. In contrast the spicules of the coenenchymal tissue are largely small capstans - short blunt-ended rods with two whorls of knobby tubercles along their length. The polyps of *P. arborea* are dimorphic in that they consist of large autozooids and minute tentacleless siphonozooids. Both types are scattered irregularly on the branches - although sometimes more crowded on one side. The autozooids are retractible into low dome-shaped calyces. The eight-lobed margin of the calyces folds over the retracted polyps forming a star-shaped operculum. The living colonies

range in color from a light tan to dark red. This species has been reported from most northern seas and is probably circum-boreal. In the western Atlantic the southern-most record is for the Baltimore Canyon. It usually occurs at depths of 100-300 fm.

In the historical survey this species was found in the axis of Norfolk Canyon between 450 and 600 m, and in the axis of Oceanographer Canyon between 700 and 1072 m. In the field study large colonies of *P. arborea* were observed between 400 and 500 m. in the axis of Baltimore Canyon. This species was also found in both Lydonia and Oceanographer Canyon between the depths of 300 to 900 m.

Anthothela grandiflora (Sars)

Briareum grandiflorum, Sars, 1856

Anthothela grandiflora, Verrill, 1879:199; 1883:40; 1922:18

Anthothela grandiflora, Deichmann, 1936:78

Anthothela grandiflora is a scleraxonian gorgonian which normally forms flat encrusting colonies. It can be found growing on stones, shells and, quite frequently, on the dead axes of other gorgonians. Occasionally developing from these encrustations are small sparsely branched upright colonies. In the latter case the central core of the branches is composed of densely packed spicules and acts as an axial support for the colonies, as in *Paragorgia arborea*. In encrusting colonies the large cylindrical calyces (3-6 mm high) are usually crowded together, but in branched colonies they can be 0.5 to 2.0 cm apart. The margin of the

calcyces is eight-lobed and the sides have rib-like striations. The polyps are usually not completely retractile and the exposed anthocodia reveal 8-10 transverse rows of warted fusiform spicules which form a collaret around the polyps and above which there are numerous tentacular spicules arranged in eight double-rows. With the tentacles contracted the spicules form an eight-rayed operculum on the top of each calyx. Spicules are also very abundant in the calyces and coenenchyme, thus giving the colony a very firm and coarse texture. The spicules are quite irregular in shape, but usually occur in the form of straight or bent, roughly warted rods, spindles or clubs. Living colonies are a light pink or salmon color. The species occurs at depths of 75 to 255 fm from Newfoundland south to Florida. It is also known from off the coasts of Europe.

This species was found in all three canyons included in the field study between the depths of 450 to 1149 m.

Acanthogorgia armata (Verrill)

Acanthogorgia armata, Verrill, 1878b:376; 1883:31
Acanthogorgia verrilli, Studer, 1901:44
Acanthogorgia armata, Deichmann, 1936:149

Colonies of these species can grow to a height of 50 cm, but most specimens are only 10-20 cm tall. The latter are generally sparsely branched - largely in one plane - with thin flexible upward curving branches. Larger colonies are more bushy. The polyps are very distinctive; they form quite long (8 mm) cylindrical calyces which stand out stiffly and perpendicularly from

the stem and branches. They are often 5 times longer than wide, and are arranged in groups which form loose spiral configurations along the length of the axis. The sides of the calyces appear striated due to the arrangement of the spicules in eight irregular double rows. The spicules are long (0.9 to 1.5 mm), slender, slightly warted rods which are usually curved or bent near the middle. At the edge of the calyx these spicules are modified into protective spines; one half of each spicule being smooth and ending in a sharp point which projects out around the open end of each calyx. The coenenchymal spicules are similar to those occurring on the lower parts of the calyx. The coenenchyme itself forms only a very thin covering over the gorgonin axis. Living colonies are a bright salmon color, but preserved material is grey or brown. The species has been reported only from the northwest Atlantic and has been found as far south as George's Bank in 300 to 640 fm.

In the historical survey *A. armata* was found throughout the study area from Corsair Canyon to Norfolk Canyon between the depths of 650 to 2150 m. This species is one of the most common corals observed during the field study, where it was found in Lydonia and Oceanographer Canyons between the depths of 400 to 1299 m and in Baltimore Canyon at 350 m.

Paramuricea grandis (Verrill)

Paramuricea grandis, Verrill, 1883:37
Lepidomuricea grandis, Verrill, 1922:16
Paramuricea grandis, Deichmann, 1936:137

Colonies of *Paramuricea grandis* are frequently 20-30 cm tall and some reach a height of 50 cm - with branches more than 1 cm thick. The branches are arranged in a loose and irregular pattern in a single vertical plane. They are short, stiff, and straight or curved towards the upper part of the colony. The polyps are distributed on all sides of the branches and tend to be more crowded together near the tips. The basal portion of each polyp is developed into a conical calyx (1-2 mm high) into which the upper portion can be withdrawn, however, the polyps are usually preserved only partially retracted - with the tentacles withdrawn but with the anthocodia exposed. The margin of the calyces is distinctly spinose. While the spicules of the coenenchyme and calyx are mostly irregularly-shaped flattened plates with incised or laciniate edges, those at the calycular margin develop a large, blunt spine at one end which projects above the calyx. Spicules are also abundant in the upper part (anthocodia) of the polyps. These are slender, curved, finely nodose spindles. The anthocodial spicules are arranged in several transverse rows which form a collaret around the polyp body. Above the collaret double rows of spicules extend into the base of the tentacles, and in contracted polyps, these form an eight-rayed spiculose operculum. The species has been found only in the northeast Atlantic from Nova Scotia to George's Bank at depths of about 200 to 950 fm. Living colonies are orange or yellow in color but they turn greyish or black in preservatives.

In the historical survey this species was found from Corsair Canyon to as far south as the Hudson Canyon area between the depths of 750 to 2150 m. Highest concentrations of *P. grandis* were found on the wall and in the axis of Oceanographer Canyon. In the field study this species was found in Lydonia and Oceanographer Canyon between the depths of 400 to 1349 m. Again, *P. grandis* was most common in Oceanographer Canyon.

Paramuricea placomus (Linnaeus)

Gorgonia placomus, Linnaeus, 1758
Paramuricea placomus, Kolliker, 1865:136
Paramuricea borealis, Verrill, 1878a:213; 1883:35
Paramuricea placomus, Deichmann, 1936:135

In its general appearance this species is difficult to distinguish from *Paramuricea grandis*. According to Verrill's original description of *P. borealis* the branches tend to be more slender, rather far apart and not very numerous. The polyps are also reported to be more spread out, however in some specimens they may be as crowded together as in *P. grandis*. The major difference between the two species lies in the spiculation. In *borealis* (= *placomus*) there are no large plate-like coenenchymal spicules, instead there are numerous, small, irregularly-shaped spinous rods. These can be curved, bent or branched and only rarely flattened like plates. As in *P. grandis* thorn-scales are present at the margins of the calyces, but these generally have smoother, more acute spines than those in *grandis*. In life the colonies are light orange or salmon in color; preserved they are

grey, brown or black. The species was originally reported from off the coast of Europe. *P.borealis* was collected from off Nova Scotia and New England in 200-300 fm.

It is impossible to distinguish between this species and *P. grandis* on the basis of photographs. However, all specimens recovered during the field study were identified as *P. grandis*. Thus, all *Paramuricea* seen in the photographs were recorded as *grandis*.

Primnoa reseda (Pallas)

Gorgonia reseda, Pallas, 1766
Primnoa resedaeformis, Broch, 1912:32
Primnoa reseda, Verrill, 1864:37; 1922:14
Primnoa resedaeformis, Deichmann, 1936:157

This species is the only primoid gorgonian found off the northeast U. S. coast. It forms large, densely and dichotomously branched colonies reaching a height of 1 m or more. The branches are crowded together and angled upward. Their axis is fibrous, solid and heavily impregnated with calcium carbonate. The basal holdfast used for attaching the colonies to hard substrates, can be almost entirely calcified. The polyps are up to 5 mm tall, are densely crowded around all sides of the branches and are fixed in a semi-extended position (curved up or down along the axis in preserved material). The polyps and coenenchymal surface have a scale-like appearance and this is due to presence of very large (1 mm or more in size) irregularly shaped spicular plates. At the top of each polyp and corresponding to the bases of the tentacles there are eight large triangular plates which fold over

the mouth of the polyp when the tentacles are retracted and thus form a conical operculum. The living colonies are light red or salmon-pink, but the colors fade to white in preserved specimens. The species occurs in the eastern and western North Atlantic generally at depths of 50 to 200 fm.

In the historical survey *P. reseda* was only found in Norfolk Canyon at approximately 400 m. In the field study this species was found at 450 m in Baltimore Canyon, and at 560 m in Lydonia Canyon.

Acanella arbuscula (Johnson)

Mopsea arbuscula, Johnson, 1862:245

Acanella arbuscula, Kukenthal, 1919:578

Acanella normani, Verrill, 1878a:212; 1883:14; 1922:44

Acanella arbuscula, Deichmann, 1936:243

As in other members of the family Isididae, *Acanella arbuscula* can be recognized by its distinctly jointed or segmented axis. The axis, which is easily seen in living colonies because of the thinness and transparency of the overlying coenenchymal tissue, is composed of two types of alternating segments: white, purely calcareous internodes and brown or amber colored nodes formed from a proteinaceous horn-like skeletal material. In *Acanella arbuscula* the base of the colony consists of a multibranched calcareous structure which acts as an anchor-like support on soft substrates. The calcareous internodes are much longer than the nodes and increase in length higher up on the colony. However, branches arise only from the nodes - three or four per node on the stem and larger branches (arranged in an irregular but somewhat spiral pattern around the axis) but only one or two per node on the

smaller upper branches. The colonies are generally not more than 15 cm high. The polyps are scattered over the branches in no regular order, two to four per internode. They stand out 2-3 mm above the coenenchyme and are covered with long, smooth or slightly spinulose spicules. The spicules around the upper margin of the polyps are developed into long projecting spines. In life the colonies are a salmon or orange color. The species has been found from Newfoundland to Chesapeake Bay in depths of 206 to 1735 fm (usually at 300-400 fm). It also occurs in the eastern Atlantic.

In the historical survey this species was found between Corsair Canyon and Atlantic Canyon, at depths from 600 to 1800 m, with highest concentrations in Corsair Canyon. A similar but more sparsely branched coral was found between 1550 and 1950 m in the southern part of the study area. Several individuals of *A. arbuscula* were found in Oceanographer Canyon between 1046 and 1191 m during the field study.

Chrysogorgia agassizii (Verrill)

Dasygorgia agassizii, Verrill, 1883:22
Chrysogorgia agassizii, Kukenthal, 1919:530
Chrysogorgia agassizii, Deichmann, 1936:233

Chrysogorgid gorgonians are characteristically very delicate looking even though some may reach a height of 30 cm or more. Their delicate appearance is due to the fineness of their branches. The colony consists of an upright stem from which spirally arranged branches extend out horizontally. The branches can be

sub-branched usually in a dichotomous pattern. The horny axis of the stem is smooth, round, and has a bronze irridescent color; that of the smaller branches is yellow or amber. The lower end of the stem is a calcareous root-like structure used for holding the colony upright on soft substrates. In preserved specimens the polyps sit as nob-like swellings 1-2 mm high on the upper or lateral sides of the branchlets. They are spaced 5-10 mm apart. The spicules are small flattened rods (up to 0.18 mm long) with rounded ends and a slightly constricted middle section. They are arranged in vertical parallel rows along the sides of the polyps and into the bases of the tentacles. The color of the polyps and coenenchyme is white. This species is known from off George's Bank in 1242 fm, and it has also been reported from the eastern Atlantic.

Several individuals that may be *C. agassizii* were found in the historical survey at 2150 m in the vicinity of Hudson Canyon.

PENNATULACEANS

Pennatula grandis (Ehrenberg)

Pennatula grandis, Ehrenberg, 1834:66
Pennatula borealis, Sars, 1856:17
Ptillela borealis, Gray, 1870
Pennatula belissima, Fowler, 1888:135
Pennatula (Ptillela) borealis, Verrill, 1883:3
Ptillela borealis, Verrill, 1922:9
Pennatula grandis, Deichmann, 1936:283

Colonies of *Pennatula* spp. are the common feather-shaped sea pens. The colony form is the result of the extensive development

of bilateral leaf-like extensions of the rachis. In *P. grandis* the colonies can be 80 cm tall and the polyp leaves 10-15 cm long. The leaves, which decrease in size towards the top of the colony, contain up to six rows of autozooids. The latter also occur on the rachis usually arranged in oblique rows. Siphonozooids can be found on the rachis, but not on the polyp leaves. The autozooids have calyces into which they can retract and the calycular margins are noticeably dentate. The spicules are small rods or needles, flattened or three-edged, occasionally twisted and usually smooth-surfaced and round-ended. The color of the colonies is orange-brown or purplish red on the edges of the polyp leaves and yellow or orange lower down and on the stalk. The species is found in the eastern and western Atlantic. It usually occurs in northern water (north of Marthas Vineyard) but has been reported as far south as the Bahamas (*P. bellissima*, Fowler). Its bathymetric range is 120 to 1255 fm.

On photographs it is impossible to distinguish between *P. grandis* and *P. aculeata*, thus all *Pennatula* individuals were recorded as *aculeata*.

Pennatula aculeata (Danielssen)

Pennatula aculeata, Danielssen, 1858:25
Pennatula aculeata, Verrill, 1873:5; 1883:2
Pennatula aculeata, var. *alba*, Verrill, 1882:310
Pennatula americana, Moroff, 1902:381
Pennatula aculeata, var. *laxa*, Verrill, 1922:2

This species is similar in appearance to *P. grandis*, but does not reach as large a size. The maximum height of the colonies is

rarely more than 30 cm. The autozooids on the leaves are arranged in a single row while those on the rachis occur irregularly on all sides except for a narrow median strip on one side. The autozooids have very distinct calyces which are quite spinose particularly along their margin. The spicules are similar to those of *P. grandis*, but unlike that species, they also occur in the tentacles of the autozooids. The color of the colonies is usually deep red or purplish, becoming lighter and more orange on the stalk and yellowish-white at the base. Pink and pure white varieties have also been reported and colonies with longer, more slender and more loosely arranged polyp leaves were described by Verrill as the variety *laxa*. The species has been reported from the northeast and northwest Atlantic. It has been found as far south as Chesapeake Bay. Its depth range is 160 to 1255 fm.

In the historical survey this species was found throughout the study area between 600 to 2500 m. Exceptionally high concentrations were found between 2150 to 2300 m in the axis of Norfolk Canyon. Several white individuals were seen on the wall of Corsair Canyon. In the field study *P. aculeata* was found between 1700 and 1799 m in Oceanographer Canyon and 350 to 1375 m in Lydonia Canyon. This species was most common in the shallow axis (400-599 m) of Lydonia Canyon.

Note: White sea pen

This sea pen is unidentified, but is similar in structure to a very fine *Pennatula*. In some areas this sea pen dominated

the shallow water fauna. No specimens of this organism were recovered during the sampling program, thus species identification cannot be made at this time. In the historical survey this sea pen was found from Veatch Canyon to Carteret Canyon at depths ranging from 100 to 300 meters. In the field study this sea pen was only found in Baltimore Canyon between 150 and 300 meters.

Distichoptilum gracile (Verrill)

Distichoptilum gracile, Verrill, 1882:362
Distichoptilum gracile, Deichmann, 1936:265

These sea pens develop into long, slender colonies (up to 50 cm high but only 2 mm in diameter) with the rachis 4 to 5 times the length of the stalk. The autozooids are placed along the rachis in two lateral rows - the polyps on one side placed alternate to those on the other. The lower 4 mm of each polyp is formed into a rigid calyx into which the tentacles and anthocodia can be retracted. Each calyx has a bilobed or forked upper edge, lies appressed against the rachis, and overlaps the calyx above it. The siphonozooids are small and few in number. There is one on either side and one above each autozoid. The spicules are smooth three-edged rods up to 0.6 mm long. The color of the colonies in life is a bright red orange. The type was collected off Nantucket in 700 fm. It has been reported from off Greenland, and the species may also occur in the Pacific.

In the historical survey sea pens resembling this species were found throughout the study area between the depths of 600 to 2500 m.

In the field study this sea pen was found in Oceanographer and Lydonia Canyons between 1100 and 1800 m depth: With this species it is impossible to positively identify specimens from photographs, thus the distribution reported in this study must be considered tentative.

Kophobelemnon stelliferum (Müller)

Pennatula stelliferum, Müller, 1776
Kophobelemnon scabrum, Verrill, 1883:7
Kophobelemnon stelliferum, Deichmann, 1936:260

Species of *Kophobelemnon* characteristically develop into club-shaped colonies 10-20 cm high. The autozooids are concentrated on the swollen upper 1/3 or 1/4 of the colony and are scattered irregularly on all sides except for a medial polypless line down the center of one side. The large autozooids (3 mm or more in diameter) are completely retractile; however, they can be preserved with part of the anthocodia exposed. Some of the polyps may be situated on calyx-like swellings of the rachis. The minute siphonozooids are scattered irregularly on the rachis and extend down the stem in somewhat longitudinal rows. Spicules occur as slender, flattened or three-edged, twisted rods with round ends and smooth or slightly nodose edges. They are up to 0.35 mm long and very abundant - giving the surface of the colony a firm coarse texture. The color of preserved colonies is light grey. The species is found in the Mediterranean, in the northeast Atlantic, in the north Pacific and in the northwest Atlantic from George's Bank to Virginia. It usually occurs at depths greater

than 500 fm, but its known range is from 215 to 2369 fm.

In the historical survey this species was most common on the slope north of Baltimore Canyon between 1550 and 1800 m depth. It was also found at 200 m north of Baltimore Canyon, between 1750 and 1900 m off Cape Hatteras and between 1300 and 1600 m in Heezen and Corsair Canyons. In the field study several individuals of *K. stelliferum* were found in Lydonia Canyon between 700 and 800 m depth.

Stylatula elegans (Danielssen)

Virgularia elegans, Danielssen, 1860:277

Stylatula elegans, Kukenthal, 1915:68

Stylatula elegans, Deichmann, 1936:270

This species forms long slender colonies on which the autozooids are arranged bilaterally. Each lateral series consists of transverse polyp rows extending around $1/4$ to $1/2$ the circumference of the rachis. There are up to six autozooids in each row and these are basally fused together and also covered by a short leaf-like fold of tissue from the rachis. Within each polyp leaf there is a fan-like group of ten or more elongate (1.5 mm) needle-like spicules. Spicules, in the form of small three-edged twisted rods (about 0.1 mm long), also occur in the tentacles of the autozooids. In an expanded state the autozooids and their tentacular crown are often very elongated. The siphonozooids are minute and barely discernable. They occur on the rachis between the polyp leaves.

Preserved colonies are a pale grey color with pale brown autozooids. The species has been reported from the northeast Atlantic and from the Caribbean. Its depth range is 15 to 550 fm. One specimen of *S.elegans* was recovered in a dredge taken at approximately 600 m in Lydonia Canyon. This is the first record of this species from the northeast coast of the United States.

Balticina finmarchica (Sars)

Virgularia finmarchica, Sars, 1851
Balticina finmarchica, Gray, 1870:13
Balticina finmarchica, Verrill, 1882:311; 1883:4
Balticina finmarchica, Deichmann, 1936:279

The long slender colonies of *Balticina finmarchica* can reach a height of 60 cm or more. The colonies resemble those of *Anthoptilum grandiflorum* - particularly in the arrangement of the autozooids which are grouped bilaterally into two series of obliquely angled rows of 1-5 polyps each. Each row converges distally with one from the opposite side of the rachis. However, in *B.finmarchica* the number of polyps per row increases in size; thus on younger colonies, or on the lower portions of older ones, the autozooids will occur singly, and higher up in pairs, on either side of the rachis. The autozooids are also characterized by a calyx, up to 8 mm long, whose margin is formed into one or two sharply pointed lobes. Around the bases of the autozooids in each row, the rachis is raised up into a leaf-like ridge of tissue. The siphonozooids are scattered irregularly

around these polyp leaves. Spicules in the shape of long smooth needles are present in the calyces of the autozooids. Living colonies are a pale salmon color with dark purplish-brown polyps. The species occurs on both sides of the north Atlantic. In the west it is found as far south as off Martha's Vineyard at depths of 60 to 980 fm.

Several individuals that may be *B. finmarchica* were found in the historical survey near Atlantis Canyon and in Heezen Canyon between the depths of 900 and 2200 m.

Anthoptilum grandiflorum (Verrill)

Virgularia grandiflora, Verrill, 1879:239

Anthoptilum grandiflorum, Verrill, 1882:312; 1883:5

Anthoptilum grandiflorum, Deichmann, 1936:276

Colonies of this species are relatively stout; they can reach a height of 35 cm but can also be nearly 1 cm thick across the rachis. The arrangement of the autozooids is similar to that in *Balticina finmarchica* colonies; the autozooids being grouped together in very irregular rows of six to eight polyps each. The groups are placed bilaterally and alternately along the rachis. The rows are angled obliquely to the axis of the pen such that the lowermost polyp in each row is located furthest to the side while the highest ones converge at the center line of the rachis. The autozooids are up to 15 mm long and are often preserved fully expanded. The small siphonozooids are scattered irregularly between the autozooids. The species is characterized by the complete absence of spicules. In life colonies are yellowish-white to deep salmon brown with brownish-red tentacles.

A. grandiflorum is distributed throughout the western Atlantic from Nova Scotia through the Caribbean to the southern tip of South America. It is found at depths of 85 to 1500 fm.

Several individuals of this species were found during the historical survey: one at 1800 m off Cape Hatteras, three at 2150 m near Atlantis Canyon and six on the wall of Heezen Canyon between 850 and 1050 m depth.

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APPENDIX C

by Barbara Hecker

Scleractinians (Stony Corals) Encountered In This Study



Thirteen species of scleractinia are known to occur, below 100 meters, in the study area (Cairns, manuscript). In contrast to many tropical shallow-water stony corals which are hermatypic (possessing symbiotic zooxanthellae), all the deep-water species are ahermatypic (not possessing symbiotic zooxanthellae). The scleractinians encountered in this study range from small delicate solitary corals to large branching colonies. These corals reproduce sexually having a motile planula larva. Some species also reproduce by asexual budding. The planulae of all of these species initially attach to hard substrates. Subsequently, several of these species detach by not reinforcing their initial attachment point. As the coral grows and becomes top heavy it breaks off and lies on the surface of the sediment (Cairns, manuscript).

Six of these thirteen stony coral species were found during this study. The taxonomy of scleractinians is based on the fine featured characteristics of their skeletons. Many of these distinguishing characters are microscopic and can not be seen in the photographs taken during this survey. As a result some of the identifications are quite tentative, particularly with regard to species of the genus *Flabellum*. Another problem to be recognized in surveying populations of these corals is that several of the species are too small to be reliably visible in photographs. The following is a brief description of the six scleractinia found in this study.

Family Caryophyllidae

Dasmosmilia lymani

This species is a small pale-orange solitary cup coral found on soft substrates. It is common on the continental shelf throughout the study area at depths ranging from 48 to 366 meters (Cairns, manuscript). *D. lymani* appears to have three methods of propagation, sexual reproduction and two types of asexual reproduction (longitudinal fission and budding from broken parental corallae). The most common method appears to be asexual budding (Cairns, 1979). As a result of this method of reproduction *D. lymani* is frequently found in very high, but localized, concentrations. In the historical survey this species was found between 100 and 200 meters on the shelf south of Hudson Canyon and in the head of Hudson Canyon. In the field study *D. lymani* was only found in Baltimore Canyon. A specimen was recovered from a ski on the camera sled that had been towed between 116 and 312 meters.

Desmophyllum cristagalli

This species is a large pale-pink solitary horn coral. It is restricted to hard substrates and is easily identified on photographs. *D. cristagalli* is frequently found in high concentrations on underhangs. This downward facing orientation probably protects the polyp from sediment loading. This species is known

to occur in the study area and is found at depths ranging from 80 to 2460 meters (Cairns, 1979). In the historical survey it was found from Heezen Canyon to Norfolk Canyon between the depths of 1050 and 1900 meters. *D. cristigalli* was usually found only in the axis of canyons, where suitable hard substrate occurred. In the field study this species was found in Lydonia and Oceanographer Canyons between the depths of 650 and 1600 meters. Specimens were also recovered in dredges from both of these canyons.

Lophelia prolifera

This species is a massive colonial coral that frequently is a main constituent of deep-water coral banks (Stetson, Squires, and Pratt, 1962). Its color is pale-pink and it forms large dendroid colonies by intratentacular budding. Growth rates for this coral are approximately 6 mm/yr (Wilson, 1979). Off the eastern coast of the United States it is known to occur from Nova Scotia to Florida between the depths of 95 to 1000 meters (Cairns, 1979). In the historical survey rubble composed of broken dead colonies of *L. prolifera* was found between 700 and 1000 meters on the west wall of Oceanographer Canyon. This rubble provided suitable attachment sites for many other organisms. In the field survey *Lophelia* rubble was recovered from dredges taken on the walls and in the axis of Oceanographer Canyon.

Solenosmilia variabilis

This species is a pale-pink colonial coral that forms large bushy colonies by intratentacular budding. The thecae of this coral are small and the calices at the end of the branches are divided. Previous to this study there was only one record of *S. variabilis* from off the northeastern United States (Cairns manuscript). In the western Atlantic its depth range is from 220 to 1383 meters (Cairns, 1979). A large colony of this species was recovered from the ski of the camera sled that had been towed from the east flank of Lydonia Canyon down into the axis. This colony was attached to several large individuals of *Desmophyllum cristagalli*.

Family Flabellidae

Flabellum alabastrum

This species is a salmon-colored solitary cup coral found on soft substrates. It is distinct from the other cup corals in that its corallum is constricted in the center. *F. alabastrum* is common throughout the study area and is found at depths ranging from 357 to 1977 meters (Cairns, manuscript). In the historical survey solitary corals that resemble *F. alabastrum* were found throughout the study area between the depths of 950 and 2300 meters. In the field study this species was only found in Baltimore Canyon between 250 and 350 meters depth. The corals seen during the field program were probably *F. alabastrum*,

since the constriction of the corallum was quite noticable in the photographs. However, some of the *Flabellum* individuals found in the historical survey may have been *F. macandrewi* or *F. angulare*. Both of these species are also known to occur within the study area, the former has a bathymetric range of 180 to 667 meters and the latter has a range of 2266 to 3186 meters (Cairns, manuscript).

Javania cailleti

This species is a small pale-pink horn coral similar in form to *Desmophyllum cristagalli*. However, its corallum is more conically shaped and has a smooth outer wall. *J. cailleti* attaches to hard substrates by a re-expansion of its pedicel into a thin encrusting sheet (Cairns, 1979). Its reported depth range is from 400 to 2165 meters (Cairns, manuscript). One specimen of *J. cailleti* was recovered in a dredge taken in the axis of Oceanographer Canyon between 935 and 1220 meters. This is the only record of *J. cailleti* from off the northeastern United States.

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APPENDIX D

Data Collection Coding Forms



Opscan Code Table

Substrate

Mud	-- 01
Sand	-- 02
Gravel	-- 03
Cobbles	-- 04
Boulders	-- 05
Outcrop	-- 06
Consolidated clay	-- 07
Talus	-- 08

Comments

Ripples	-- 01
Scour	-- 02
Overhang	-- 03
Associations	-- 04
Dead?	-- 05
Tracks	-- 06
Garbage	-- 07
Coral Rubble	-- 08
Shell hash	-- 09

Observers

Hecker	-- 1
Blechsmidt	-- 2
Gibson	-- 3

Species code list

Urchins	--001	<i>Bathynectes superba</i>	--110
<i>Araeosoma fenestratum</i>	--139	<i>Cancer borealis</i>	--018
<i>Echinus affinus</i>	--002	<i>Geryon quinquedens</i>	--019
<i>Echinus alexandri</i>	--003	Hermit crab	--135
<i>Hygrosoma petersi</i>	--004	<i>Homarus americanus</i>	--072
<i>Phormosoma placenta</i>	--005	<i>Lithoides agassizii</i>	--017
		<i>Munida valida</i>	--020
Brittle stars	--006	<i>Munidopsis rostrata</i>	--074
<i>Amphilimna olivacea</i>	--008	<i>Parapagurus</i> sp.	--021
<i>Asteronyx loveni</i>	--054	Pink galatheid crab	--122
<i>Ophianax</i> sp.	--128	Pink shrimp-like crab	--130
<i>Ophiocantha</i> sp.	--039	Shrimp	--113
<i>Ophiomusium armigerum</i>	--052		
<i>Ophiomusium lymani</i>	--007	Polychaetes	--022
<i>Ophiura</i> sp.	--140	<i>Hyalinoecia artifex</i>	--023
		Crowned polychaete	--120
Starfish	--010		
<i>Asterias vulgaris</i>	--142	Gastropod	--121
<i>Astropecten americanus</i>	--011		
<i>Benthopectin spinosis</i>	--143	Cephalopods	
<i>Dytaster grandis</i>	--060	Octopus	--102
<i>Freyella</i> sp. A	--056	Squid	--103
<i>Freyella</i> sp. B	--057		
<i>Henricia</i> sp.	--131	Sponges	--024
<i>Hymenaster</i> sp.	--157	<i>Cladoriza</i> sp.	--047
<i>Mediaster bairdii</i>	--058	<i>Hyalonema</i> sp.	--025
<i>Pectinaster forcipatus</i>	--141	Lettuce sponge	--076
<i>Plutonaster intermedius</i>	--061		
<i>Porania</i> sp.	--063	Fish	--049
<i>Porcellanaster caeruleus</i>	--012	<i>Antimora rostrata</i>	--152
<i>Pseudoarchaster pareli</i>	--062	Brotulid	--155
<i>Psilaster florae</i>	--144	Chimerid	--151
<i>Solaster benedicti</i>	--059	Flounder	--105
<i>Tremaster mirabilis</i>	--158	Hake	--138
<i>Zoroaster</i> sp.	--123	<i>Halosauropsis rostrata</i>	--154
		Rattail	--136
Holothurians	--013	Ray	--115
<i>Euphronides</i> sp.	--014	Rosefish	--147
<i>Mesothuria lactea</i>	--064	Shark	--153
<i>Paelopatides gigantea</i>	--015	Skate	--107
<i>Peniagone</i> sp.	--116	<i>Synaphobranchus kaupi</i>	--137
Lemon cucumber	--124		
		Pycnogonid	--031
Echinoderms		<i>Colossendeis colossea</i>	--032
<i>Brissopsis</i> sp.	--125		
Stalked crinoid	--119	Anemone	--027
		<i>Actinauge longicornis</i>	--029
Crustacea	--016	<i>Actinoscyphia saginata</i>	--030
<i>Acanthocarpus alexandri</i>	--071	<i>Bolocera tuediae</i>	--060

Anemones (continued)

<i>Cerianthus borealis</i>	--112	<i>Primnoa reseda</i>	--034
Cerianthid anemone	--028	<i>Protoptilum carpenteri</i>	--086
Anemone A	--068	<i>Radicipes gracilis</i>	--083
Anemone B	--069	<i>Scleroptilum</i> sp.	--088
Anemone C	--070	<i>Trachythela rudis</i>	--129
Anemone E	--106	<i>Umbellula lindahli</i>	--037
<i>Actinauge verilli</i>	--067	<i>Virgularia mirabilis</i>	--089
White avalanche anemone	--150	Pink column	--117
		White sea pen	--132
Hydroids	--134	White stalked pen	--118
Stalked thing	--109	Yellow gorgonian	--127
White hydroid	--111	Sea pen	--146
		Sea whip	--104
Hard corals	--042		
<i>Caryophyllia ambrosia</i>	--094	Miscellaneous	
<i>Dasmosmilia lymani</i>	--096	Golf balls	--048
<i>Desmophyllum cristagalli</i>	--043	Burrows	--051
<i>Enallopsamnia profunda</i>	--100	White feather (sponge)	--126
<i>Flabellum alabastrum</i>	--044		
<i>Flabellum angularis</i>	--099		
<i>Fungiacyathus fragilis</i>	--097		
<i>Javania cailleta</i>	--095		
<i>Lophelia prolifera</i>	--045		
<i>Solenosmilia variabilis</i>	--101		
<i>Vaughanella margaritata</i>	--098		
Soft corals	--033		
<i>Acanella arbuscula</i>	--050		
<i>Acanthogorgia armata</i>	--114		
<i>Anthomastus agassizii</i>	--035		
<i>Anthomastus grandifloris</i>	--036		
<i>Anthoptilum grandiflorum</i>	--090		
<i>Anthothela grandiflora</i>	--149		
<i>Balticina finmarchica</i>	--091		
<i>Callogorgia gracilis</i>	--093		
<i>Chrysogorgia agassizii</i>	--082		
<i>Distichoptilum gracile</i>	--087		
<i>Eunephthya fruticosa</i>	--040		
<i>Eunephthya florida</i>	--148		
<i>Eunephthya glomerata</i>	--156		
<i>Funicularia quadrangularis</i>	--085		
<i>Keratoisis ornata</i>	--078		
<i>Kophobelemnnon stelliferum</i>	--084		
<i>Lepidicus caryophyllia</i>	--077		
<i>Metaligorgia splendens</i>	--081		
<i>Narella laxa</i>	--080		
<i>Paragorgia arborea</i>	--041		
<i>Paramuricea grandis</i>	--039		
<i>Pennatula aculeata</i>	--038		

LAMONT-DOHERTY GEOLOGICAL OBSERVATORY

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APPENDIX E

Technical Aspects

by

William B.F. Ryan

Gretchen Blechschmidt

Peter R. Thompson



TECHNICAL ASPECTS

Navigational Capabilities

One of the prime technical objectives of the field program was to undertake photographic coverage of the seabed at locations sufficiently well determined so that the locations could be re-occupied and observations repeated in the future. The stringent navigational requirements seem justified by the patchiness of many of the sessile benthic communities. The principal tool of the biological survey was our bottom-towed sled whose cameras record a distant field of view approximately 5 meters in width along transects that extended from 1 to 12 km in length.

In order to satisfactorily accomplish the objectives of precise navigation, a goal was set to first locate the surface vessel in an absolute geodetic reference frame and then to position the on-bottom sled with respect to the surface vessel. For ease of correlation to existing industrial and other national bathymetric surveys of the outer continental shelf we chose the Universal Transverse Mercator coordinate system as the reference frame. A scale of 1:48,000 was adopted for real-time shipboard navigation; Figure E-1 shows a segment of a typical shipboard track. We later enlarged our maps to 1:24,000 for the post-cruise analysis and synthesis.

Our philosophy of design and assembly was one of a total integrated system consisting of several navigation sensors interfaced to a digital computer with graphics display. For Leg E-2A-79 at Baltimore Canyon and E-2B-79 on Georges Bank,

the navigational sensors on the R/V Eastward.

1. velocity tracking with doppler sonar (resolution of 0.1 knots);
2. gyro-heading (resolution of 0.5% of arc);
3. continuous Loran-C auto tracking of four master-slave pairs on the East Coast U.S. networks 9930 and 9960 (resolution of .01 microseconds);
4. doppler positioning using four polar-orbiting Navy Transit satellites (accuracy of 0.2 mm);
5. radio ranging from two temporary shore installations to a resolution of 0.01 lanes (= 0.9 meters), having the commercial name of ARGO.

The highest degree of repeatability is provided by radio-ranging. The ARGO equipment was loaned by NOAA and shore stations were set up at Avalon, New Jersey and Asseteague, Delaware. At the operational frequency of 1868 kHz, a wavelength (or lane) is approximately 90 meters in length. Because the shipboard master station simply measures a phase difference, this technique only has the capability of determining fractional wavelengths (or fractional lanes). Whole lane counts are determined from an autolane counting capability. However, difficulties were encountered with the whole lane counts as the consequence of unexpected brief but complete interruptions in the radio transmissions. Further, the ARGO system was not operated for Leg E-2B-79 at Oceanographer and Lydonia Canyons because of the significantly greater propagation distances from potential land

stations.

A general practice in offshore radio-positioning is for the survey vessel to return to an exactly determined location (dock, buoy, tower) once the lane count is lost. We found that we could circumvent this time-consuming practice by combining Loran-C measurements with satellite measurements. We were able to obtain up to 100 simultaneous Loran-C and satellite fixes during each canyon survey. Propagation corrections for Loran-C were calculated so as to place the Loran-C positions exactly in the center of the field of scatter of a plot of the highest quality satellite fixes, edited for elevation, number of doppler counts, and reasonableness of computer heading and speed. We found that this satellite Loran-C calibration could be used to find the whole lane count of the ARGO system. The lane count procedure involved a statistical matching of approximately 1000 simultaneous Loran-C and ARGO fixes (at 5 minute spacings), which showed that the Loran-C standard deviation from ARGO was equal to 0.64 of an ARGO lane.

A final confirmation of the correctness of the whole lane count was made by comparing the initial first-day calibration of ARGO at the Chesapeake Light Tower with a last day fix at the U.S. Coast Guard dock at Cape May, New Jersey. The through-cruise tie turned out to be consistent within the integrity of a single lane, and the fractional lane difference amounted to less than 4 meters (most likely the accuracy of the initial calibration while circling the Chesapeake Light Tower at a safe distance of several boat

lengths).

For Leg E-2A-79 at Baltimore Canyon we believe that we accomplished a continuous near surface positioning with a standard deviation of ± 5 meters for approximately 85% of the time while surveying and for more than 95% of the time when actually towing or sampling on station. For Leg E-2B-79, where we could only rely on the Loran-C satellite calibration, the navigational precision degraded. For illustration purposes, Figure E2 plots for Julian Day 139 the latitude and longitude differences between 14 simultaneous satellite and Loran-C fixes. For the entire Leg the mean difference in latitude was 104 meters and in longitude was 127 meters. The largest differences were experienced around sunset and at sunrise, due to propagation anomalies.

Sled Navigation

The on-bottom tracking of the towed camera sled is determined relative to the surface vessel using a combination of acoustic slant ranging and internal on-bottom dead-reckoning. For this purpose the sled was outfitted with a synchronous pinger and a self-recording digital depth, heading and speed sensor package. Its magnetic heading was converted to true heading using the current measured magnetic deviation. A schematic diagram of the ship and camera sled system is shown in Figure E3. The horizontal range from ship to sled (Fig. E4) was calculated from the acoustic slant range (corrected for seawater sound velocity) and the pressure depth (corrected for temperature and salinity effects to

the net water density). Pressure depth had the largest uncertainty in measurement primarily because our pressure gauge had a resolution of 7 meters and a repeatability of 3% of the total depth range. As a consequence, along some of the deepest tracks, such as in Oceanographer Canyon, the pressure depths differed from the sonic depth by as much as 20 meters.

Following the computation of the horizontal separation of the ship from the sled, a horizontal range circle was plotted at each 5 minute advance of the ship track. Since camera runs were made at speeds of 0.8 to 1.2 knots, there is a horizontal range circle for approximately each 150 meter segment of the track. The size of the horizontal range circle is dependent on the speed of the ship and the camera sled. Photographs were automatically taken every 15 seconds. Thus, one picture is taken for each 8 meter segment of the track, and there is a new range circle calculation for about every 20 frames. The determination of the point that the sled track intersects each circle was achieved using two approaches. The first involves computation of the physical forces acting on the towed cable with knowledge of the details of the surface track, the length of cable and the depth of the sled. The second was the dead-reckoned sled track computed entirely from the on-board dead-reckoning sensors. A computer program was devised which fits the dead-reckoned sled track to the every sixth range circle and compares the deviation from all the in-

between range circles. The adjustment required for the best fit to each range circle is attributed to transient effects of near-bottom currents causing the sled to record an apparent velocity that equals sled velocity plus current velocity. The offset vector is graphed at each 15 or 30 minute interval as a means to assess the local variation in bottom current speed and direction.

Cross-track uncertainty is judged to be about 5 times larger than along-track uncertainty, since the sled tracks within a 15° angle from the stern of the surface vessel. Our calculations allow us to estimate the cross-track uncertainty to be on the order of 3% of the water depth. Exact checks are made when sled transects intersect previous tracks at near right angles. As an example, during Camera Run #6 in Baltimore Canyon the acoustic navigation could be used to predict the recrossing of a sled mark. Study of the film revealed the marks to be within 2 frames of the predicted frame (a distance of 12 meters.)

The important consideration is that all the navigation has been accomplished in an absolute geodetic reference frame. Therefore, cross-track calibrations take into consideration the total accuracy of the entire geodetic calibration and not just a measure of the ship to sled ranging.

When the camera sled is in contact with soft substrates ski imprints are made and, judging from experience with past submersible dives, these tracks can be expected to have

variable lifetimes from perhaps only a few hours on current swept sandy surfaces to dozens of years on muddy slopes isolated from active scour. We have a fairly high level of confidence that our sled tracks can be relocated and individual photo sites revisited in the future by employing navigational capabilities of the same degree of accuracy as those used here. Operations in the future would be all the more feasible if the revisiting is made by a manned submersible capable of recognizing key landmark marks recorded on our films.

Camera Sled Operation (see also Fig. 4 of Final Report)

The camera-sled ("Cheep Tow") used in the BLM field program was designed specifically to be towed in contact with the bottom on rough terrains. It employs a welded aluminum frame fitted with buoyant spheres so as to be both self-righting and to have only about 20 kg of bearing weight on the substrate. Its righting movement prevents it from being tilted by more than about 15° from the horizontal as long as there are no net lateral torques on the skis.

To decouple the sled movement from the vertical motion of the surface vessel, it is towed behind a 500 kg depressor on a 100 meter tether of neutrally buoyant polypropylene line. Swivels are mounted both where the line attaches to the sled and also at the depressor. The depressor is towed with a 1/2" diameter steel cable from the ship's trawl winch. The two cable passes through an accumulator to

remove some of the vessel's heave and roll.

In standard configuration the sled is equipped with:

1. one high capacity 35 mm camera (400' film reel);
2. one 250 watts/sec. strobe;
3. one logic package (responsible for electronic timing, synchronization and distribution of power);
4. one self-recording navigation and oceanographic sensor package
5. one synchronous pinger;
6. two 12 volt, wet cell battery packs.

All but two of the instrument housings are constructed of aluminum alloy for lightness. The sled's overall negative buoyancy and its lateral trim are adjusted by small removable lead weights. The fully equipped sled weighs approximately 250 kg out of water.

For the BLM field study the logic package was timed to trigger the camera and strobe at an exact 15 second repetition interval using crystal-controlled digital circuitry.

The time of day to the nearest second was optically registered in digital format adjacent to each film frame.

Pressure depth, magnetic heading, speed through water, temperature, and conductivity were recorded on 1/4" magnetic tape at 2 minute intervals. The pinger transmitted at 12 kHz at 1 second intervals with a mercury contact switch set up to cause it to double ping if the sled tilted by more than 30°.

A second pinger was mounted on the trawl wire at 50 meters above the lead depressor. Travel time from this second pinger to the bottom was used to continuously monitor the height of the depressor above the sea bed. Echos from the depressor can be detected down to water depths as great as 1000 meters, allowing the depressor to be towed at a well determined elevation. In general, at a tow speed of 1 knot the camera settles to the bottom when the depressor is within 50 meters of the bottom. Settling rate of the sled is 35 meters/minute which equates to a descent angle of 50 degrees. The descent rate is a function of the amount of negative buoyancy. As adjusted for the field program, the sled would not track effectively down slopes steeper than about 45°. The ability to track downslope is also a function of the depressor elevation. Attempts to fly the depressor only a few meters above the bottom literally pull the sled downhill. Such low flying is risky, however, because it reduces the ability of the tow cable to pull the sled free of obstacles that might entangle it (ledges, large boulders, abandoned traps, etc.)

The percent of time in contact with the bottom changes from run to run depending mostly on bottom roughness, operator experience, and water depth. In benign terrains, such as thalweg floors or flat shelves, the bottom contact might exceed 80% of the time. During transects along gullied canyon walls it may be reduced to less than 40% of the time.

Acoustic Profiles

Three simultaneous acoustic profiles were obtained (Fig. E5). One was made by the ship using the hull-mounted transducer. It sonifies a strip of seafloor as wide as about 40% of the water depth. The second was made by the pinger above the depressor. At a depressor elevation of 20 meters, this second sound source sonifies a strip of seafloor about 40 meters wide. The third profile was made directly from the sled. The pinger here has its transducer mounted some 10 cm above the base of the skis so that when the sled is in contact with the bottom a very narrow track is being explored. A sub-bottom profile is generated from the sled pinger with a penetration that ranges from 1 to 2 meters down to 20 meters in well-stratified soft material.

The three profiles permit geological features to be observed over a wide range of sizes and wavelengths. Furthermore, since the depressor is 100 meters ahead of the sled, the operator has an early warning of features to be encountered by the sled, giving her/him time for reaction and planning to maximize sled contact with minimum risk of hang-up or equipment damage. The double ping ($>30^\circ$ sled tilt) capability allows the surface vessel to reverse course or stop altogether, often before significant additional tension is observed on the tow cable.

Field of View

At typical tow speeds of 0.8 to 1.2 knots the camera

advances approximately 8 meters over the seafloor between consecutive frames. With the 250 watt/second strobe, the camera's visible horizon is at a distance of approximately 5 meters. About 60% of track is photographed with about 40% of it being at light levels sufficient for scientific analysis.

The camera is mounted at an angle of 12° down from the horizontal. Its lens has a focal length of 35mm, giving a field of view of $54^{\circ} \times 33^{\circ}$ at f 4.5. With ASA 200 Ektachrome color transparency film, we used a shutter speed of 0.1 sec. and aperture settings between f 8 and f 11 to reduce lens curvature distortions. The focus was optimized for objects at a distance of 1.8 meters from the lens. The lens is at a height of 0.7 meters above the seafloor when the sled is in bottom contact. The strobe is at the same height above the bottom as the camera, but is separated horizontally from the camera by a distance of 0.6 meters, causing some backscatter in turbid water while maximizing the evenness of the light field.

The strobe is mounted to the right of the camera giving the viewer of the film the impression of a low sun angle over the right shoulder. Oblique angle pictures enhance the ability to make biological identifications and to discriminate geological bedforms and bottom textures. The major serious disadvantage of oblique photography is the inability to accurately estimate the exact area of the region being photographed (see discussion in Hecker, Blechschmidt and

Gibson, this volume).

The sled can also be equipped with a 70 mm (100' film reel) camera. This type of camera was used initially for the first three camera runs. We soon switched to the higher capacity 35 mm camera, so as to allow for significantly longer camera tows.

All film was developed shipboard within hours of the camera's arrival back on deck. The film was custom processed in 50' segments in order that development time could be individually adjusted to actual exposures.

Sled Problems Encountered

The most serious "Cheep Tow" difficulties were experienced with the lead-acid battery power supply. A major unforeseen problem arose where the sled would hang-up on some obstacle and either tip over on its side or invert all together despite the flotation devices. This appears to have allowed the pressure compensation oil to coat the battery plates, thereby greatly reducing the total amp/hour capacity. The coating effect turned out to be cumulative, and we were forced to retire batteries sometimes after only a couple of lowerings. Toward the end of the second leg we ran out of replacement batteries and had to recycle former rejects. Draining of the battery acid and washing of the cells did not appreciably renew the battery capacity. For the latter part of Leg E-2B-79 useful camera footage was terminated midway during several of the runs by premature

depletion of power. The cure in hindsight would have been simply to stock a larger supply of fresh batteries, perhaps of a different nature.

Another problem encountered in deploying the camera sled was the failure of the transponder navigation system. The Interocean Acoustic Transponders and Releases intended for our use were delivered too late to be adequately tested prior to our field program. Unfortunately, during the first leg (E-2A-79) of the cruise, we found that the acoustic release mechanism was faulty. After several shipboard dry runs we made an attempt at a sea trial. The release mechanism of the test transponder failed to work, and the transponder was lost. In order to retrieve it, we deployed a CTFM transducer at the site to find the transponder during future submersible operations. Although the transponder was sighted during this program, technical difficulties made it impossible to recover the transponder without endangering the submersible.

Subsequent tests of the system in similar situations has shown that transponder navigation is probably not as reliable in shallow waters as other navigational methods because of error introduced when the length of the transponder base line is the same as the water depth. In the case of our canyon study, the base line was on the order of one to two thousand meters, and the water depth was not greater than 1,500 meters. Also the steepness of the canyon walls and the narrowness of the canyon axes tend to introduce side echos which further increase the unreliability of this method.

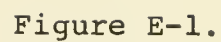


Figure E-1.

Typical segment of a cruise track, here in Oceanographer Canyon, showing the density of the bathymetric profiling network.

27'

26'

E-15

40°25'
68°6'

7'

8'

9'

10'

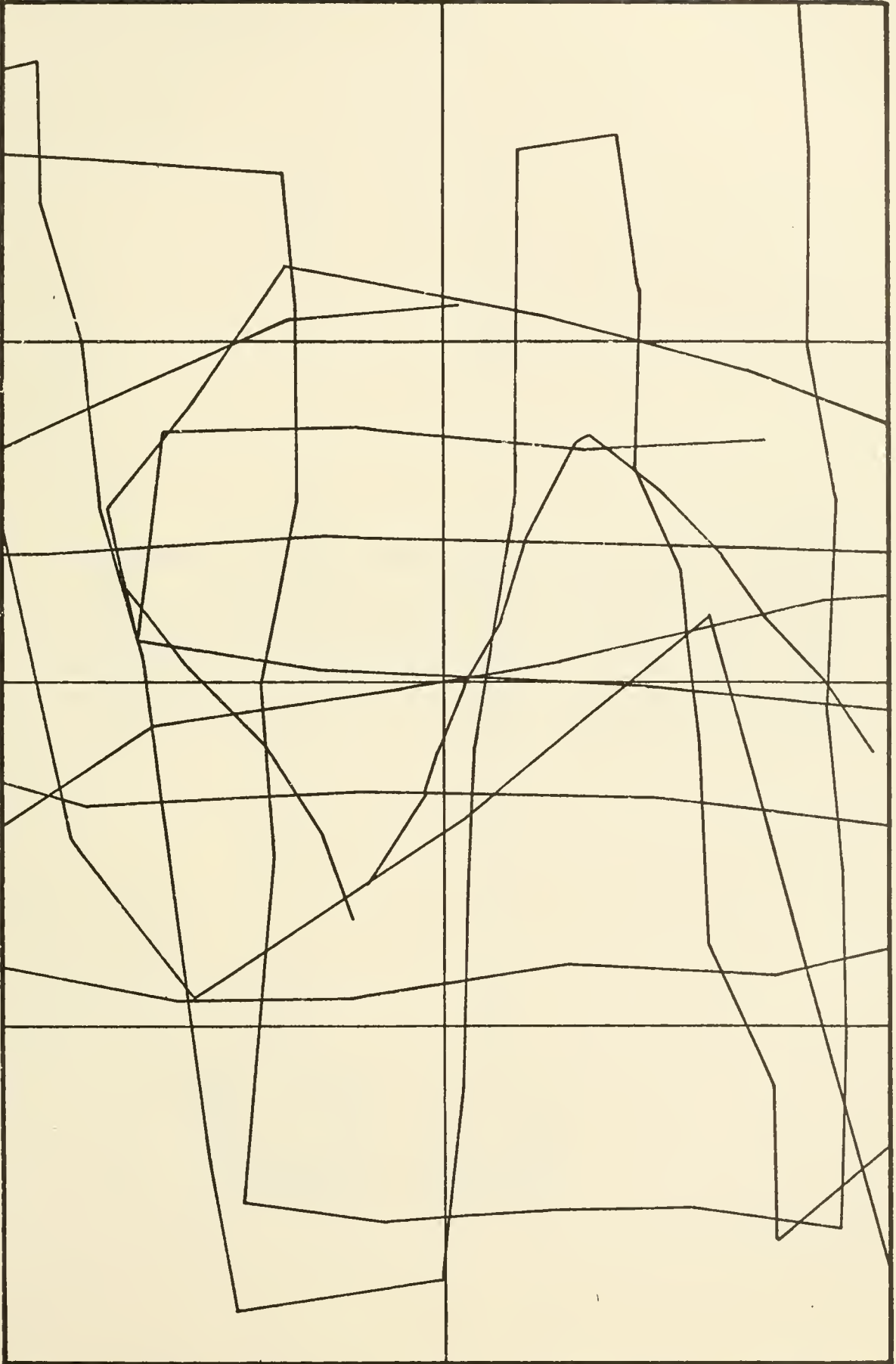


Figure E-2.

Latitude and longitude differences for 14 simultaneous Loran C and satellite navigation fixes during Julian day 139. Tick marks along the horizontal axis represent hours. The vertical scale is ± 200 meters of difference.

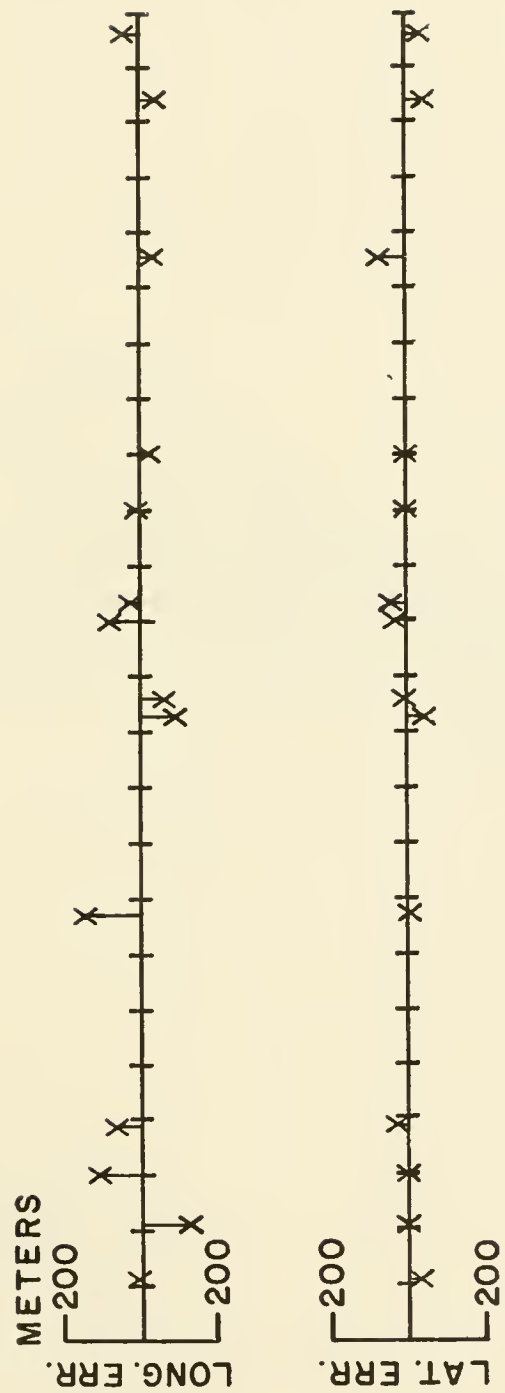


Figure E-3.

Schematic diagram of the relative ship and camera sled positions during a camera run. Arrows indicate the direction of the pinger signals from the depressor and the camera sled.

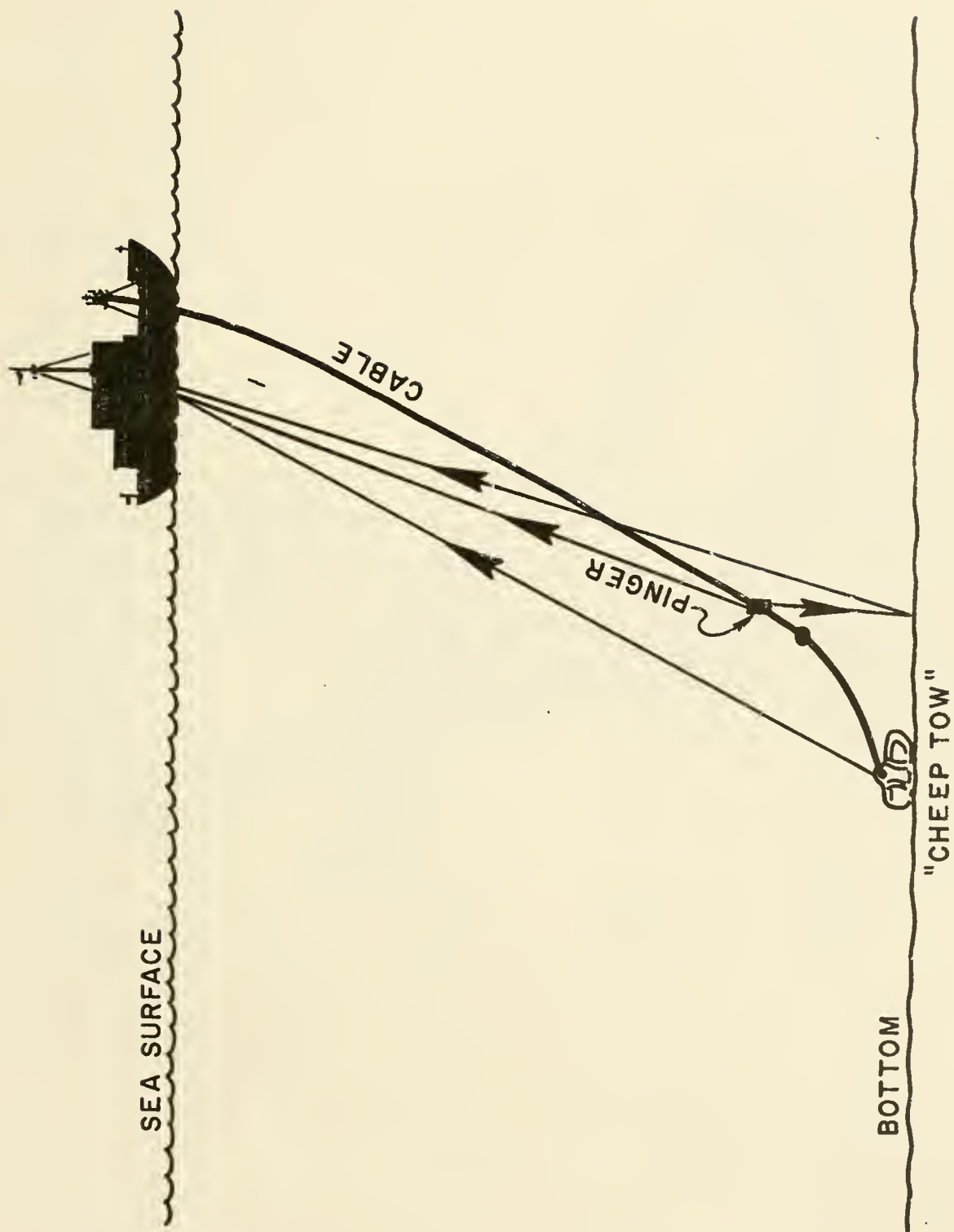


Figure E-4.

Ship track during Camera Run 6 showing typical horizontal ranges (circles) for 5-minute intervals. The diameter and spacing of the circles is determined by the relative speeds of the ship and the camera sled.

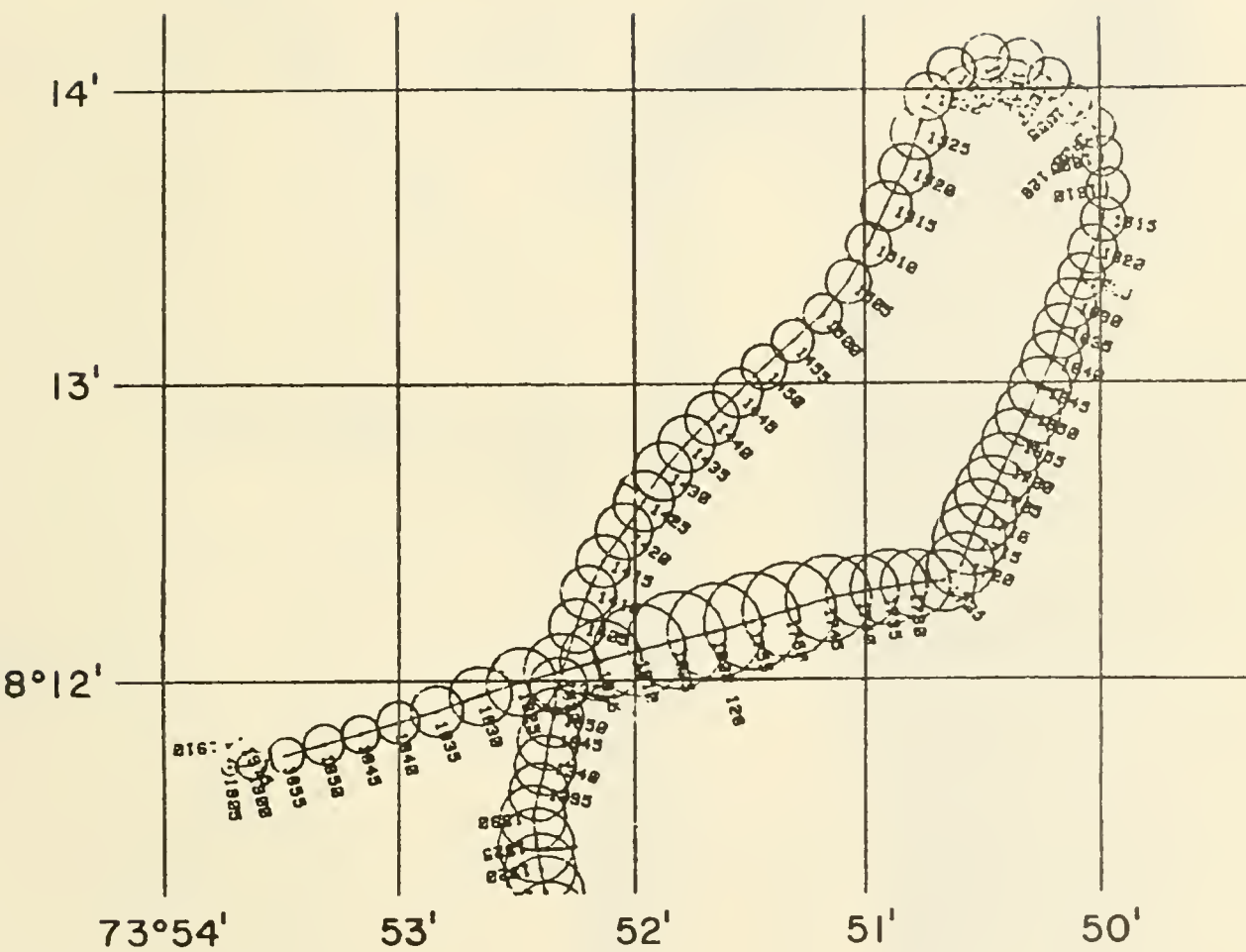
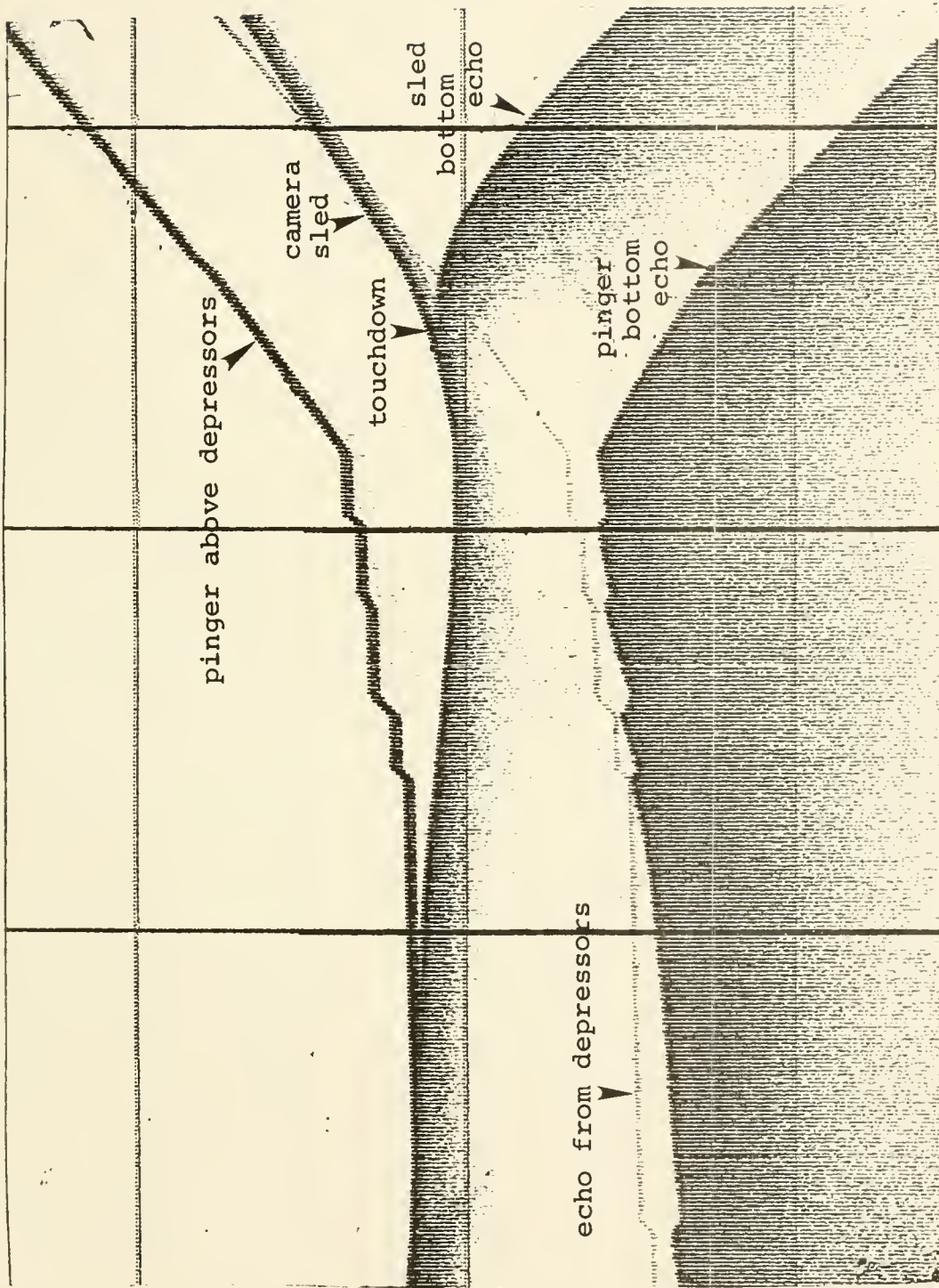


Figure E-5.

Acoustic profile showing bottom echoes and pinger traces for depressor and sled pingers at touchdown.



APPENDIX F

East Coast Submarine Canyons

by

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Gretchen Blechschmidt

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EAST COAST SUBMARINE CANYONS

Introduction

North of Cape Hatteras, the U.S. East Coast continental margin is characterized by an abundance of submarine canyons incised into the continental shelf and slope. Emery and Uchupi (1972, Fig. 44, 46) list 46 canyons off the eastern North American margin and estimate at least 190. Detailed bathymetric surveying for diverse purposes is to this day identifying previously unrecorded smaller canyons and tributaries. At the same time, seismic reflection surveys along the continental margin are recognizing numerous buried channels clearly connected to rivers indicating that both constructional and erosional processes operate during the life of the canyons (Shepard, 1952; Rona, 1970).

Ample studies on both the U.S. east and west coast (see Shepard, 1973) demonstrate that submarine canyons are the main conduits for sediment transport from the shelf to the rise and ocean floor. That these conduits also move nutrients can be recognized by the richer populations of fish and invertebrates inhabiting these areas (Barham et al., 1967; Sanders and Hessler, 1968; Rowe, 1971; Tietjen, 1971), than in intercanyon areas. On the other hand, submersible observations within canyons have called attention to large talus blocks and thick sand deposits (Trumbull and McCamis, 1967), which certainly represent periodic scour affecting a portion of the organisms present.

In order to make meaningful interpretations from the

"Cheep Tow" census presented in this report, we have made a superficial survey of the geological literature of the east coast submarine canyons intending to distinguish regional and local faunal/substrate associations. For example, the observation of a given invertebrate does not permit the automatic conclusion that it is related to the temperature of the water alone: it could equally be present or absent in response to nutrient availability, current velocity, substrate hardness, or any combination of these. If, on the other hand, a regional biological survey such as presented elsewhere in this report, recognizes broad regional gradients in biological populations to which each canyon contributes detail, those ecologic conclusions drawn are strengthened.

Most of the geology of continental margins has been investigated by two methods: direct observation/sampling by submersibles and coring/dredging operations, and through acoustical surveys relying on interpretation of refraction and reflection profiles. In addition to these standard techniques, the canyons mapped during the field program were investigated by 12kHz echo sounding along precision navigated tracks. The tracks were aligned both parallel to and orthogonal to the overall canyon trend. The tracks were spaced a distance equal to 50% of the local water depth of the canyon in order to totally sonify the seafloor. Such echograms reveal not only the gradients of the canyon walls, but the complex areal distribution of the side tributaries. Additional bathymetry was obtained directly from the 100 km of

on-bottom towing of the canyon sled. The sled was equipped with a digital pressure gauge and another 12 kHz sound source in order to provide a limited subbottom definition and a crisp bottom profile undistorted by side-echoes. Many of the sled tracks were oriented parallel to the contours for the purpose of crossing canyon tributaries. The tributaries have only minor relief of a few meters to a few tens of meters, but along the canyon walls they are boldly incised as V-shaped gullies. The only tributaries with flat floors are the major ones originating on the slope outside the canyon area or those having a distant seaward confluence with the main canyon. Such major tributaries have their own second and third order tributaries.

Sediment sampling of continental margin outcrops and surface veneer has long suggested that these materials constitute the submarine extension of coastal plain formations. Basement rocks of the East Coast are pre-Carboniferous metamorphic and igneous rocks, and down-faulted troughs filled with Triassic rocks (Emery and Uchupi, 1972). Unconformable on this basement are consolidated Jurassic to early Pleistocene sediments blanketed by a late Pleistocene to Holocene cover of unconsolidated sediment. Drake et al. (1959), interpreting deep seismic refractions north of Cape Hatteras, delineated two linear accumulations of sediments, one under the present shelf and one under the base of the slope. They inferred that the sedimentary accumulation beneath the shelf was comparable with the classic miogeosynclinal structures while the accumulation near the slope might be the

eugeosyncline.

More recently, multi-channel seismic reflection surveys have shown numerous prominent reflectors at great depths along the continental margin, leading to estimates of up to 12 km of sediments lying beneath the shelf off New York (Schlee et al., 1976). Drilling of the COST B2 well off New Jersey (Smith et al., 1977; Scholle et al., 1977) penetrated 4.8 km of Mesozoic and Cenozoic sands and shales interpreted as having been deposited in shallow water environments. This volume of sediments, along with numerous geophysical measurements over the years, has prompted investigations seeking subsidence mechanisms besides simple sediment loading of geosynclines. It seems likely that much of the excessive subsidence of the Baltimore Canyon trough is due to crustal thinning related to the initial opening of the Atlantic some 200 m.y. ago. Steckler and Watts (1978) have summarized the hypotheses for crustal thinning into three main groups: 1) subcrustal cooling and thinning at the time of rifting; 2) crustal stretching due to regional extension and marginal loading; and 3) deep metamorphism increasing crustal density.

The Georges Bank depocenter, represented here by the Oceanographer and Lydonia Canyons, is located in an area of lesser subsidence than Baltimore Canyon. Strata of similar age are much shoaler than in Baltimore Canyon. As a result, backcutting of Baltimore Canyon has exposed formations only younger than 25 m.y.B.P. (Gibson et al., 1968), whereas the Oceanographer and Lydonia Canyons have excavated many geological formations that are typically as old as 95 m.y.B.P.

(Stetson, 1949; Gibson et al., 1968; Ryan et al., 1978).

The origin of submarine canyons has received considerable attention in the geological literature of the past 50 years. Two categories of theories have emerged from a large number which have been proposed (Shepard, 1973, pp. 327-334): 1) the canyons were originally seaward extensions of now-drowned river valleys which have been maintained by sub-aerial erosion such as turbidity currents; and 2) the river valley walls have been built up by preferential sedimentation.

Most , if not all, of the east coast submarine canyons can be shown to be extensions of major U.S. rivers, thought to have been more active during late Pleistocene low sea-level stands. In glaciated areas, diversions to meltwater flow were provided by cuestas and moraines (McMaster and Ashraf, 1973). In some instances, the direct link between river and canyon has no modern bathymetric expression due to post-glacial shelf sediment movements, although shallow seismic studies have revealed buried channels (Pratt, 1967; Knott and Hoskins, 1968; Knebel et al., 1979).

All the canyons appear to have high leveed right banks (Pratt, 1967). Rona (1970) has proposed a sedimentation model for canyons, supported by reflection data in his and other studies, in which intercanyon areas are sedimented while the canyons themselves are swept free of sediment. The resulting strata become convex upward and geostrophic contour currents (Heezen et al., 1966) preferentially depo-

sit sediments on the up-current (right bank) side.

Flushing/erosion of submarine canyons seems to be a complex process. Cascading of cold dense water in the vicinity of the canyons may be locally important (Cooper and Vaux, 1949; Iselin, 1963). Turbidites cored at the bases of many parts of the rise attest to occasional turbidity current activity (Ericson et al., 1961), but may not necessarily be responsible for the deep incision observed. There is growing evidence that up- and down-canyon tidal flow is effective in moving fine grained sediments down canyons (Shepard and Marshall, 1978; Keller and Shepard, 1978).

Baltimore Canyon

The Baltimore Canyon (and related Wilmington Canyon) is located off Chesapeake Bay. The region is tectonically quiescent, and is situated south of the area directly affected by Pleistocene glacial advances. The surface of the outer shelf in the area is relatively smooth. The upper portions of both canyons trend southward to about the shelf/slope break at about 70-80 m, and then abruptly turn southeastward across the slope. The axis of the Baltimore Canyon is concave upwards (Fig. F1) but is broken by changes in axial gradient. Kelling and Stanley (1970) observed that both axial gradients and changes in course take place at similar distances from an arbitrary point along the margin, suggesting large scale structural and/or lithologic controls.

The head of Baltimore Canyon cuts some 18 km landward

from the regional shelf edge. The overall gradient of the thalweg is 2.8° , debouching onto the continental rise at a depth of about 1.5 km. The floor of the canyon is rather flat and about 400-500 m wide. Where explored by this project, the floor is covered by ripple-marked, well-sorted sand and silty clay.

The shelf edge strata of the Baltimore Canyon trough consist of sigmoidal-shaped foreset depositional units (Schlee, 1978a). These units represent a period of substantial shelf progradation since the early Miocene (approximately 25 m.y.B.P.). As sampled by coring and dredging during the field program (Tables F1 and F4), these units are fine grained and loosely consolidated, primarily sand or mud rich in mica and quartz, with accessory clay, siliceous microfossils and abundant authigenic glauconite. They drape over older materials of consistently finer texture (silty mud).

The upper canyon walls contain several oblong-shaped terraces. Kelling and Stanley (1970) postulated that two sets of benches at depth ranges of 100-110 m and 128-146 m were wave-cut Pleistocene shorelines. Some of these benches are up to 370 m wide, and show a consistent depth at their outer margins when traced laterally. In our high-resolution reflection profiles, however, these terraces appear instead to be the tops of back-tilted fault blocks that have slipped downwards towards the canyon axis.

Subbottom profiling with the camera sled in Baltimore Canyon provided new data to show that many of the side tri-

butaries are dusted with a thin (1 - 8 m) drape of acoustically homogeneous sediment. The photo sled observations showed that most of the tributary walls do not have outcropping strata in contrast to the abundant outcrops along deeper reaches of the thalweg walls. We believe that much of the dendritic drainage network is relict, and thus inactive at present. We also note that the numerous cross-canyon profiles (Fig. F-2) show a steepening of the lower canyon walls when compared to the upper canyon walls.

All of the echograms obtained in our field program were studied for their reflectivity character. Areas of inferred outcrop or shallow subcrop were mapped on the basis of reflectivity. These studies are essentially distributions of various acoustic patterns that we have related to local canyon bedforms. In all canyon studies, the outcrops recognized by acoustic mapping occur along narrow sinuous belts adjacent to or at a short distance from the central thalweg, in some instances 50 m or more above the edge of the thalweg floor. The thalweg and the outcrops are separated by gently dipping sediment ramps and fans. The outcrops form cliffs 100-200 m in height. They are exposed along the edges of all the major slope tributaries, but seldom occur along the second or third order tributaries. Large talus blocks are very rare in the thalweg area, although some relatively fresh avalanche debris was observed on the canyon wall. Our mapping indicated that the central area has experienced a relatively recent phase of axial excavation which seems

to have directly followed the phase of activity that produced the dendritic drainage network. In Baltimore Canyon, the axial downcutting phase has been superceded by a phase of axial filling, leading to the formation of the broad thalweg floor.

Kelling and Stanley (1970) noted four reflector zones in their study of the Baltimore Canyon. Their uppermost group of reflectors is thick (105-150 m), and is discordant with the group beneath. The second reflector interface appears to have an angular contact, while the lowermost interface is concordant but represents a lithological break rather than a stratigraphic discontinuity. When Kelling and Stanley's cross-sectional profiles are compared to our survey to locate surface exposures of these reflectors, the topmost discordant contact intersects the thalweg axis at about 190 m, the angular contact is at about 230 m, and the lowermost contact is at about 470 m. Outcrops noted in the camera sled survey are consistently located in the lower reflector zones.

Paleontologic determinations by Stetson (1949), Gibson et al. (1968), and in this report (Tables F1 and F4) are all Pleistocene to Recent in age. These materials are almost entirely clays, silts and sands, and were collected from the veneer layers or the thalweg floor cover. Correlation of reflectors to other adjacent areas by Kelling and Stanley (1970) led them to conclude that their middle reflector zones were middle to upper Tertiary, and the lowermost zone

Eocene or upper Cretaceous. The COST B2 well slightly to the east placed the top of the Eocene at 4092 ft (1237 m), considerably deeper than the lowest reflector interface. The dredges or cores taken in the Baltimore Canyon at depths less than 1.3 km by any of the surveys that actually sampled the outcrops have failed to produce sediments that are very old. On the nearby slope, materials as old as Eocene (40 m.y.B.P.) have been recovered at DSDP Sites 107 and 108, and in rock dredges at depths below 1.8 km.

Oceanographer and Lydonia Canyons

The shelf-edge strata of Georges Bank are planar, gently seaward dipping top-set depositional units (Emery and Uchupi, 1972; Schlee et al., 1976; Schlee, 1978b). They represent a period of up-building with little seaward progradation, a style which has been persistent since the Mesozoic (100 m.y. B.P.). The outcrop strata in the Oceanographer and Lydonia Canyons are not only coarser than those of the Baltimore Canyon, but at equivalent burial depths, they are also appreciably more indurated. Furthermore, the Georges Bank region received substantial amounts of Pleistocene age glacial outwash and locally transported glacial erratics giving this region an anomalously high abundance of gravel, cobbles and boulders.

Oceanographer Canyon cuts more than 30 km into the continental shelf; Lydonia cuts 20 km. Both canyons debouch onto the continental rise at depths greater than 2 km.

Their overall thalweg gradients exceed 3° (Fig. F4). Back-tilted terraces are much more limited than at Baltimore Canyon, and are confined to the canyon head areas (Fig. F3, F5). The floor of the thalwegs of Oceanographer and Lydonia Canyons are seldom more than 50 m in width, whereas Baltimore commonly exceeds 400 m. As in Baltimore Canyon, Oceanographer and Lydonia Canyons have numerous lateral second and third order tributaries, in most instances originating below the shelf edge at depths generally greater than 200 m. The heads of the tributaries are shallowest in Lydonia Canyon.

In Oceanographer and Lydonia Canyons, axial downcutting seems to be still active, and the floor of the thalweg is littered with numerous talus blocks (Trumbull and McCamis, 1967, Ryan et al., 1978), recently avalanched from the outcrop belts. Here, outcrops extend almost always right down to the edge of the thalweg floor. In our field program, we sampled these outcrops (Tables F2, F3), finding good agreement with the fossil ages determined by pervious samplings by Stetson (1936, 1949) and Gibson et al. (1968).

The Cretaceous age at most of the Oceanographer Canyon axial outcrops suggests that these indurated strata are bedrock exposures rather than downdropped allochthonous units of the canyon wall. Upper Turonian (95 m.y.B.P.) outcrops in Oceanographer Canyon occur at depths below 950 m and in Lydonia Canyon below 600 m. We also sampled indurated sediments belonging to Coniacian, Santonian, Campanian, and

Maestrichtian stages of the Upper Cretaceous; with the dredging technique it is difficult to place exact limits on the depths from which the rocks have been recovered. We know for sure, however, that latest Cretaceous materials (65 m.y.B.P.) occur as shallow as 585 m in Oceanographer Canyon from dredge 10-36 of Stetson (1949). From seismic reflection profiles run parallel to (Roberson, 1964) and ours perpendicular to the shelf edge, horizons dip seawards. We estimate that the top of the Cretaceous descends from a depth of 500 m beneath the head of Oceanographer Canyon to a depth of 900 m near the regional shelf edge.

A particularly important observation is that younger rocks can be found in verifiable outcrop position at greater depths than older rocks (see Ryan et al., 1978, Fig. 6). For example, Pleistocene sandy mudstone occurs in well-stratified benches at depths in excess of 1500 m along the margin of the Oceanographer thalweg axis (Fig. F4). Paleocene rocks occur at a depth of 950 m and Cretaceous rocks occur at depths shallower than 800 m. The apparent stratigraphic inversion of essentially autochthonous formations is, in our opinion, reasonably explained with the working hypothesis that the canyons have experienced previous periods of cut and fill, going back into the Mesozoic. We consider it important evidence that, when younger rocks are found deeper than older rocks, their facies and their benthic micro-faunas almost indicate non-neritic and mid-slope to bathyal depositional environments.

According to our hypothesis, the shelf edge of Georges Bank experienced canyon cutting as far back as the Santonian (80 m.y.B.P.). The Cretaceous materials sampled at depths below that of the Santonian are interpreted as outcrops of post-Santonian canyon fill: they are composed of micaceous siltstones and silty marlstone with planktonic foraminifera. In contrast, the older rocks are coarse arenites and cemented conglomerates of inferred fluvial or littoral origin. The Paleocene and Eocene samples are also likely to be deep water in origin because of their high planktonic/benthonic microfossil ratios. They consist of graded calcareous grainstones, possibly laid down by turbidity currents. They are also considered to be canyon fill.

Bathymetry

One of the primary geological objectives of this project was to construct detailed bathymetric maps of Baltimore, Oceanographer, and Lydonia Canyons. In order to accomplish this, we did a detailed acoustic profile of each canyon within the navigation net discussed in Appendix E. The resulting bathymetric maps are shown in Figs. F-1, F-3, and F-5. Examination of these maps shows that each of the three canyons has a unique configuration.

Baltimore Canyon (Fig. F-1) is characterized by a fairly broad, flat thalweg with sloping walls. The canyon is oriented northwest to southeast from head to mouth. There are many small tributary channels on the walls. At approximately 500 meters depth in the axis there is a sharp bend of the

thalweg to the west going up-canyon. Dredging and photography revealed that there are solid rock outcrops at this point. Figure F-2 shows a perspective view of cross sections of the canyon along a straightened axis. The locations of the transects are shown on Fig. F-6.

Oceanographer Canyon (Fig. F-3) is the most deeply incised of the three canyons. The thalweg is narrow and curves slightly northwest to southeast from head to mouth. The walls of the canyon are quite steep with numerous small side tributaries. There is a large secondary channel to the east of the thalweg, debouching into the canyon at about 1600 meters depth in the main axis. The perspective view along a straightened axis of the canyon is shown in Fig. F-4.

Lydonia Canyon (Fig. F-5) is the smallest of the three canyons. The thalweg is quite narrow, particularly in the lower part of the canyon. The walls are generally steep with a slight increase in slope just above the thalweg. As in Baltimore and Oceanographer Canyons, the walls are incised by numerous small side tributaries. The walls of some of the side tributaries are also quite steep.

Methods

Sediments were recovered by day dredging and gravity coring during the field program of this study. These materials were analyzed sedimentologically and biostratigraphically. The location of gravity cores, dredges, and camera runs in the three canyons is shown in Figs. F-1, F-3, and F-5.

Thirty-five gravity cores were split, measured, and described according to standard L-DGO procedures. Samples were taken from the tops and within each core. Each sample was analyzed for size distribution. The greater than 63 micron fraction was determined by wet sieving. The carbonate content of core tops was measured by manometer recording the amount of carbon dioxide released by HCl. Dredge samples were archived and sampled for similar analysis as well as coarse fraction studies and smear slide analysis. Different samples from the same dredge were given letter designations. All the dredge samples were also analyzed biostratigraphically using foraminifera and calcareous nannofossils. Samples were disaggregated using Calgon and wet sieved at 63 microns for foraminiferal analysis. Smear slides and light microscopy were used for the calcareous nannofossil age determinations. For the most part, a magnification of 1000X was used.

Additional geologic information was obtained from the photographic record and from acoustic characteristics of the substrate. This information is particularly helpful in that coring and dredging cannot provide complete coverage of the canyons. Also failure of the ship's radar system during cruise E-2B-79 made it impossible to carry out a coring program in Oceanographer Canyon. Because of our position in crowded Georges Bank shipping lanes and inclement weather (fog) the chief scientists and ship's officers felt it was too dangerous to continue. Sediments from dredges in this canyon were sampled and analyzed in order to obtain some geologic information. Unfortunately the dredges fre-

quently covered a wide depth range and several canyon environments, so that it is difficult to make specific conclusions based on sediment analysis alone.

Results

Baltimore Canyon

The distribution of sediments and outcrops in Baltimore Canyon is shown in Fig. F-6. This map is based on acoustics and photographic coverage. Thin strips of outcropping rock are seen along the walls of the thalweg and at the sharp bend in the axis at 500 meters previously described. Another area of exposed outcrop was noted on the west flank of the canyon where talus blocks were also found during the photographic survey. Photo analysis shows that sediments in the thalweg are rippled. Mollusc fragments are common in the thalweg and in shelf deposits recovered in cores and dredges. Analysis of cored sediments indicates that the thalweg and shelf sediments are sandy with sand percentages as high as 81.5%. Sediments on the walls tend to be poorly sorted silts (Fig. F-7). Several deposits of clay were noted during the photo survey, but only clay sediment was recovered in only one core. This may be due to a bias introduced by the difficulty in coring hard clay deposits. A complete listing of core data from Baltimore Canyon may be found in Table F4. Sediments recovered in dredged samples are similar to those found in cores. Rocks were recovered in a number of dredges in Baltimore Canyon (Table F1). For the most part, these were found in the area of the sharp curve in the axis. These rocks are generally hard glauconitic siltstones, sandstones,

and conglomerates. Some of the siltstones and sandstones are fossiliferous, containing pelecypod casts and fragments. In the other area of outcrops noted on the west wall mudstones and hard clays were recovered.

The carbonate content of the core tops is listed in Table F4. In general carbonate values are fairly low, ranging from 1% to 14%. The carbonate component is for the most part biogenic (foraminifera, coccoliths, and shell fragments) with minor detrital carbonate.

Biostratigraphic analysis of dredged material indicates that most sediments are of Quaternary age. The rock samples contain no age diagnostic microfossils. Benthic foraminifera found in a number of samples indicate a mid-bathyal depth range.

Oceanographer Canyon

Figure F-8 shows the distribution of sediment types and outcrops in Oceanographer Canyon based on acoustic profiling and the photographic record. Outcropping strata were noted along the walls of the thalweg and in the tributary channels. Camera runs in the vicinity of the thalweg revealed that the canyon walls are quite steep. Minor areas of exposed outcrop were also noted on the east wall of the canyon. The floor of the thalweg itself is sandy and rippled. Three major areas of avalanche scars were determined with the acoustic record. These are near the base of the canyon.

As no cores were taken in Oceanographer Canyon, we were forced to rely on dredged samples to determine the nature of the sediments. This factor introduces a bias into the data in that sandier sediments are lost in the dredging process.

The percentage of sediment greater than 63 microns is listed in Table F2. The values range from 2% to 33% of the total sediment. Based on our observations in other canyons the sand content should be much higher in the thalweg and on the adjacent shelf. A number of our dredges intersected the thalweg but no sand was recovered. Because of this we conclude that our sediment sample is not totally representative in this canyon."

Rock samples were recovered in most of the dredges taken. These include siltstones, sandstones, mudstones, and conglomerates. A listing of sediment and rock types is given in Table F2. Much of the sandstone and siltstone recovered is dark grey to black, micaceous and glauconitic. An organic carbon analysis was performed by George Claypool of the U.S.G.S. on two samples of this material. The organic carbon content was found to be 1.2% which is above average in marine sediments. However, the analysis indicates almost no hydrocarbon generating potential.

The carbonate content of the dredged muds varies considerably with values ranging from 0.7% to 22%. The carbonate component is comprised of foraminifera, coccoliths, and shell fragments. In general, the carbonate percentages are somewhat higher in the older rocks than in the Quaternary muds.

The dredged rocks range in age from upper Turonian (approximately 95 m.y.B.P) to Quaternary. The glauconitic micaceous sandstone and siltstone described above are of Turonian and Santonian age. An upper Miocene siltstone (6 m.y.B.P.) was recovered in Dredge 20. In general the older material was not

recovered in dredges shallower than approximately 800 meters. Unconsolidated sediments are all Quaternary. Much of the dredged material is barren of age diagnostic microfossils.

Lydonia Canyon

Examination of the acoustic profile and the photographic records shows that the walls of most of the mid and lower canyon are comprised of outcropping or subcropping strata (Fig. F-9). These outcrops are also seen in small side tributaries. The area of exposed outcrop appears to be less toward the head of the canyon. The narrow thalweg floor is sandy and rippled. A broad area of cobbles and boulders was noted on the lower east flank of the canyon. A similar smaller patch was also noted on the west flank.

Sediment analysis of the cored materials shows that the surface sediment is generally fairly sandy both on the canyon walls and in the thalweg. Figure F-10 shows the size distribution of core top (surface) sediments. Sand percentages as high as 87% were noted in the thalweg. By and large, thalweg and shelf sediments in Lydonia Canyon are well sorted sands, while wall sediments are sandy silts (Tables F3 and F5).

Rocks dredged in Lydonia Canyon are very similar to those recovered in Oceanographer Canyon. The dark grey micaceous glauconitic siltstone found in Oceanographer Canyon was also found in Lydonia Canyon, as well as the upper Miocene siltstone. This finding is not surprising considering the proximity of these two canyons. Biostratigraphic analysis supports the correlation of rock units between the two canyons. The dredged material was dated as Turonian and upper Miocene.

One sample of white marl was recovered on the ski of the camera sled. This yielded an age of mid Eocene.

The carbonate concentration in sediments recovered is generally quite low with values ranging from 0.8% to 7.6%. The carbonate component is comprised primarily of biogenic material (foraminifera, coccoliths, and shell fragments) with some detrital carbonate.

Current Velocity Measurements

Submarine canyons have long been recognized as the conduits for sediment movement from shelf areas to abyssal plains; currents along the canyons have also been considered as having an active role in sediment movement. Long-term monitoring studies have identified both up- and down-canyon flow in canyons whose reversals coincide with diurnal tides for the west and east coasts of the U.S. (Shepard and Marshall, 1978; Keller and Shepard, 1978). The net bottom transport is down-canyon, however, resulting in fans at the base of the canyons containing sands, graded bedding and shallow water shells (Ericson et al., 1961; Horn et al., 1971). Some debate has continued concerning active erosion indicated by bare bedrock as opposed to low current velocities indicated by very fine silts and clay. Lydonia Canyon seems to be an exception to most northeast U.S. canyons in that its cover of fine-grained sediment displays little or no current activity (Ross, 1969). On the other hand, currents as high as 75 cm/sec have been recorded in Hydrographer Canyon and between 100-200 cm/sec in a turbidity current in Oceanographer

Canyon (Keller and Shepard, 1978).

Although the first in situ submarine canyon measurements were made in Lydonia and Gilbert Canyons (Stetson, 1937), most direct measurements have been made offshore from California. Trumbull and McCamis (1967), however, measured a down-canyon velocity of 10 cm/sec in Oceanographer Canyon using Alvin, and observed no sediment motion. Keller et al. (1973) found comparable velocities of 8-15 cm/sec in Hudson Canyon clearly displaying reversals of flow. Reversals have also been described from Hydrographer, Wilmington, Washington, and Norfolk Canyons (Shepard and Marshall, 1978; Keller and Shepard, 1978).

In order to investigate the relationships of sediment movement and canyon faunas, we calculated bottom current velocities for 17 of the camera sled transects investigated. The current speed is measured from a Savonius rotor mounted 1.3 meters above the bottom of the sled ski. Current direction is measured by magnetic compass with a resolution of 1.0 degree. The currents have been tabulated for each approximately 1/2 hour segment of on-bottom track. The current vectors are shown as wind-rose diagrams in Figs. F-11-13 and by arrows on each of the three station maps, Figs. F-1, F-3, and F-5, (the length of the arrow is proportional to the current speed and its orientation shows the current direction).

The measured currents have a mean velocity of 25 cm/sec. In each of the three canyons they show a more or less normal distribution centered around the mean velocity. The maximum velocities are 50 cm/sec. The velocities greater than 40

cm/sec may be spurious caused by tugs on the sled which cannot be resolved in the navigated sled track. Mean velocities are least in Oceanographer Canyon (Fig. F-12) and greatest in Lydonia Canyon (Fig. F-13). The currents in Baltimore and Oceanographer Canyons have a dominant flow direction towards the ESE and the NE. For the same regions of the canyon current vectors are consistent from one sled track to the next. At the sled track intersection the directions have a mean deviation of 25° . Direction changes are attributed to diurnal tidal variations which in Baltimore Canyon are exemplified by the current changes seen along Camera Run #6. The measured currents tend to flow down canyon walls and up and down canyon axes. Oceanographer Canyon shows a strong cross-canyon flow towards the east, a feature observed in Hydrographer Canyon (Keller and Shepard, 1978). In Lydonia Canyon the common current directions are SW and WNW. The change here to westerly direction may be explained by the fact that the camera runs were during different parts of the diurnal cycle than the runs in Oceanographer Canyon.

Since the directions vary with the tidal cycle and since the sled measures only the instantaneous current vector, current directions are ephemeral and should not be given too much significance. Current velocities measured during the field program, however, are consistently higher than those measured by long term moored arrays in Hydrographer Canyon (Keller and Shepard, 1978). The higher velocities might be attributed to our instrument. The Savonius rotor has a certain amount of inertia and if the towing causes strumming on the rope,

this high frequency motion might be transferred to the rotor. Post-cruise calibration of the meter was consistent to within 2 cm/sec. over the range of 1-50 cm/sec.

The measured velocities are sufficient to transport silts and fine sands in traction bedload. The detection of strong currents on both the walls and in the axial thalwegs is consistent with the photographic observations of exposed outcrops or rippled surfaces in both areas. Although Ross (1969) concluded that a blanket of fine-grained sediment in Lydonia Canyon was indicative of little or no current activity our measurements show that adequate transport velocities are commonly reached. It is indeed possible that local topographic features interfere with seasonal thalweg velocities and down-canyon transport of sediment.

Temperature and Salinity Measurements

In situ temperatures and salinities were measured in all three canyons using thermistors on the camera sled and by expendable bathythermographs. The sled system provides a temperature reading for every 2 minutes of the sled run. This translates to a measurement approximately every 50-75 meters along the sled track. Bathythermograph profiles were made in each canyon, one in the shallower head of the canyon and one in the deeper mouth of the canyon (Fig. F-14). Both profiles were centered over the thalweg. A thermal maximum is seen at a depth between 100-150 meters. The maximum is approximately 12°C and marks the top of the permanent thermocline. A $7-8^{\circ}\text{C}$ minimum occurs at a depth

of about 40 meters and this depth is shallower than any of the substrates photographed.

At the equivalent depths, the temperatures in the heads of Oceanographer and Lydonia Canyons tend to be slightly warmer than at locations lying further seaward. The permanent thermocline descends to a depth of approximately 100 meters where the temperature is about 6°C . The coldest temperatures are 4°C at the depth of 1390 meters in Lydonia Canyon.

The salinity is uniform at approximately 35 ± 0.1 ‰. It shows very little variation with depth or position in the canyons. Salinities are highest (35.3 ‰) on the shallow rim of Baltimore Canyon and lowest on the shelf (34.8 ‰). This range of values is typical of open marine conditions, and does not reflect any freshwater input.

Summary and Conclusions

We interpret the dendritic drainage patterns of the Baltimore, Oceanographer and Lydonia Canyons (believed to be typical of all East Coast submarine canyons) to have been formed in the Quaternary during periods of low sea stands. The dendritic incision would have accompanied the important continental margin regressions such as that experienced with the expansion of the Wisconsin ice sheet between 25,000-11,000 y.B.P. An ancestral dendritic pattern may have originated as far back as the first major cooling in the Late Pliocene at about 3 m.y.B.P. Eustatic sea-level lowerings

as great as 170 m would have turned the canyon areas into near coastal estuaries, thus allowing sediment to be introduced from numerous local sources around the estuarine shore. The dendritic pattern is interpreted as a morphologic development of landward erosion towards numerous sources all along the canyon rim, rather than focused into the modern canyon head.

The sea-level rise accompanying glacial retreat should have caused the canyon rim sources to disappear. Initially the canyon head would have been fed by streams emanating from glacial moraines surrounding glacial lakes. Such leveed channels can be recognized in the shallow subsurface seismic profiles of Knott and Hoskins (1968) and Knebel et al. (1979), although they have been buried in time. The present source of material to the canyon head includes migrating sheet sands transported in fraction by oceanic circulation on the drowned shelf.

We have encountered relict gravel and cobble pavements along the Georges Bank canyon rims and active sand flows in the canyon head. The modern canyons are essentially funneling systems and the dominant bypass route is the thalweg floor. In Oceanographer and Lydonia Canyons the funneling is sufficiently strong to both prevent the formation of a wide thalweg surface and to keep the base of the canyon wall actively scoured and undercut. Polished rock surfaces are commonplace as are overhanging ledges of indurated sediments. The 1977 diving program with ALVIN (Ryan et al., 1978) re-

ported the presence of cataracts and submarine "splash pools" along the thalweg axis.

The funneling process is believed to be the one responsible for the post-dendritic axial downcutting. Our sled photography, and especially the sled pinger profiles, show the lower reaches of the side tributaries often to be truncated near the point that they would have debouched into the central thalweg. We have submersible photographs of portions of the truncated cross-sections of some tributaries showing that the side streams have been abandoned as "hanging valleys" in glacial terrains on land. Because the tributaries in canyon mid-slope regions are draped with more than one meter of mud, they attest to a recent inactivity in the dendritic system.

As discussed under Oceanographer Canyon, our observation and sampling of younger rocks in outcrops at greater depths than older rocks is considered evidence for additional previous intervals of canyon cut and fill going back into the Mesozoic. Subsequent fillings have later been incised, and we believe that the deepest excavation is the latest one.

The distribution of outcrop within a canyon system is temporal in nature. During the phases of canyon filling, outcrops may have disappeared completely. Because certain of the sessile communities have a preference for indurated or partly indurated substrates, the extent of outcrop is important if one wished to infer the broad regional distributions of the attached organisms. Our photo sled documented

the macro-benthic community only along the individual tracks. Furthermore, the sled is difficult to maintain in bottom contact on the particularly steep slopes where most of the outcrops occur. The photography is thus somewhat biased against recording outcrop and may overemphasize the substrates lacking outcrops.

The outcrop as mapped acoustically, is much more extensive than the outcrop mapped photographically (which may be covered by only a thin veneer of sediment). The acoustic outcrop has been verified only locally by dredging, by the few submersible transects particularly along the thalweg edge, and by sled photography. The distribution pattern of the present outcrop is that which was produced by the recent phase of axial cutting.

Slumping of surficial thin sediment aprons is not prevalent within the canyon proper, probably because of the presence of indurated older material at shallow burial depths. Large-scale surficial slumping has been detected only near the mouth of Oceanographer Canyon and along the adjacent external slope. Tear-shaped patches of small-scale roughness occur here at depths below 1000 m. They are interpreted tentatively as slump scars and have the associated chaotic debris flow deposits. Their locations correlate with those parts of the margin where the younger sediments have their thickest expression. The largest slide blocks in Baltimore Canyon also correlate with the presence of exclusively young and more loosely-consolidated materials.

The attempt to map outcrop and erosion patterns from our field study data should be considered preliminary. Near bottom side-scan sonar is a much more appropriate mapping tool than vertical incidence profiling. We would expect that side-scan surveys would reveal greater plan-view detail and more variability in the outcrop pattern. An important conclusion to be drawn from our preliminary mapping, which we believe would also be supported by side-scan surveying, is that outcrop is not pervasive throughout the entire canyon system. In fact, it is probable that less than 20% of the canyon area exposes either outcrop or contemporary erosional surfaces.

All three east coast canyons studied are active in the sense that they are bypass routes for traction transported sediments. Parts of the canyon walls are being kept free of sediment by contemporary currents. We would not expect to see a major difference in the way the three canyons distribute material injected by offshore development activities. We would anticipate that materials which enter from the margins would eventually become entrapped in the second and third order tributaries. Hereon it would await further down-slope transportation, most likely confined to the small V-shaped valleys. We would not expect these materials to come in contact with the steep outcrop belts lining the central thalweg unless they were injected as suspensions. Materials entering the canyon head should rapidly pass into the central thalweg and then eventually bypass the entire canyon

enroute to the continental rise. Such materials, if they were more fine grained than the thalweg sands would winnow from the sands and exit the canyon quickly in the net downcanyon current transport (Keller and Shepard, 1978). One of the best analogies that we have for comparison is the natural dumping of ice-rafted sediment in the Georges Bank region. From all the evidence at hand, the ice-rafting material resides today on the surface segregated in local areas. It is mostly concentrated as gravel lag deposits adjacent to the shelf edge along the canyon rim (Stanley and Wear, 1978) down to depths of about 250 m, but occasionally found within tributaries to depths in excess of 600 m. The high frequencies used in side-scan sonar would be especially effective for mapping the present gravel distribution.

The three canyons discussed here represent different depositional environments which are reflected in their sedimentary characteristics. In general Oceanographer and Lydonia Canyons are quite similar with considerable exposed outcrop and sandy sediments. Baltimore Canyon, on the other hand, has only local exposures of outcrop and more poorly sorted silty sediment. The carbonate contents of Oceanographer and Lydonia Canyons are also similar. Average carbonate values in these canyons is consistently lower than those found in Baltimore Canyon. These results indicate that the Georges Bank Canyons represent a more active environment of non-deposition or reduced deposition while Baltimore Canyon represents an environment of active sediment deposition.

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Figure F-1.

Bathymetric map of Baltimore Canyon showing core, dredge,
and camera run locations.

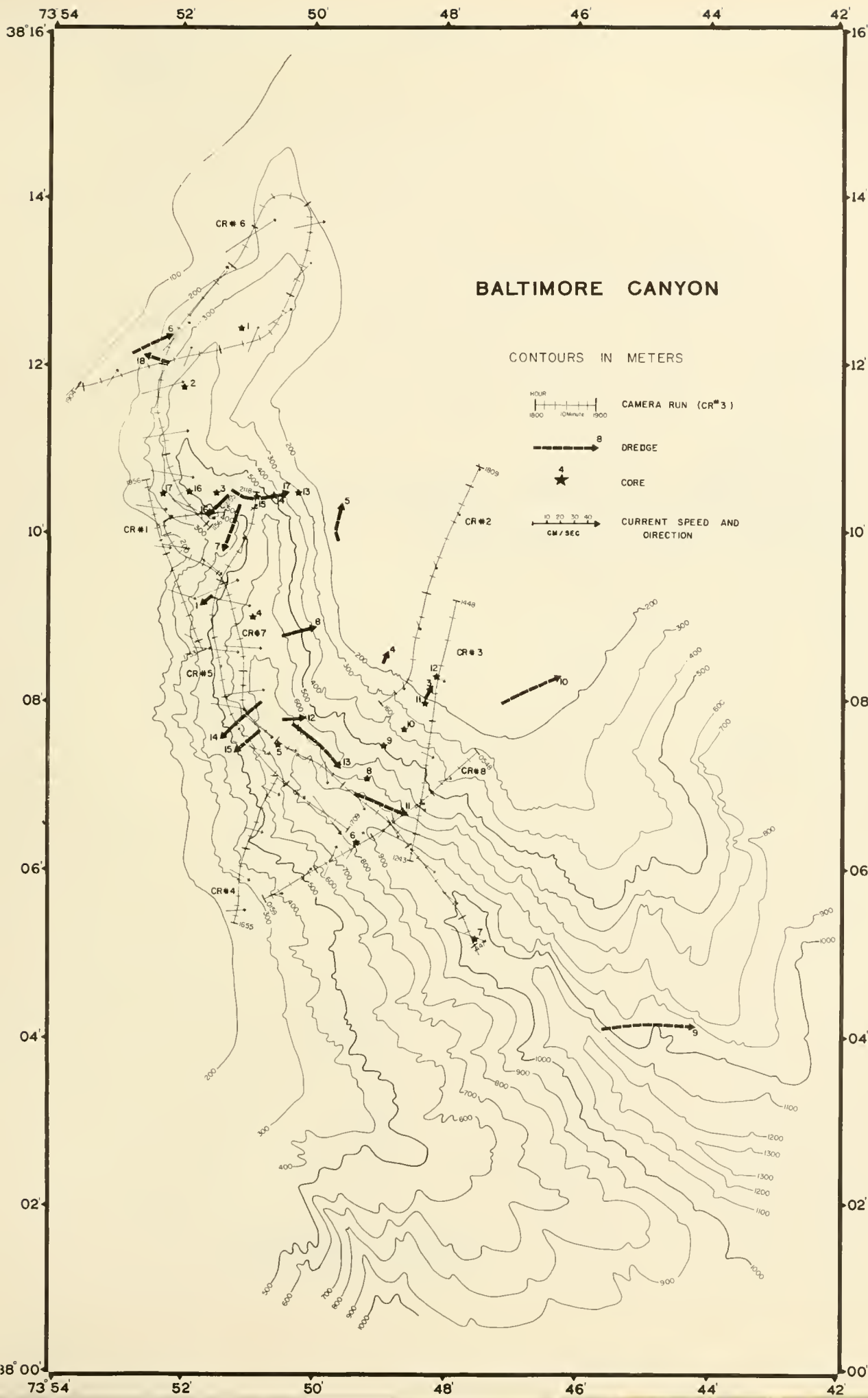


Figure F-2.

Cross-sections of Baltimore Canyon aligned at the thalweg to show the bottom configuration.

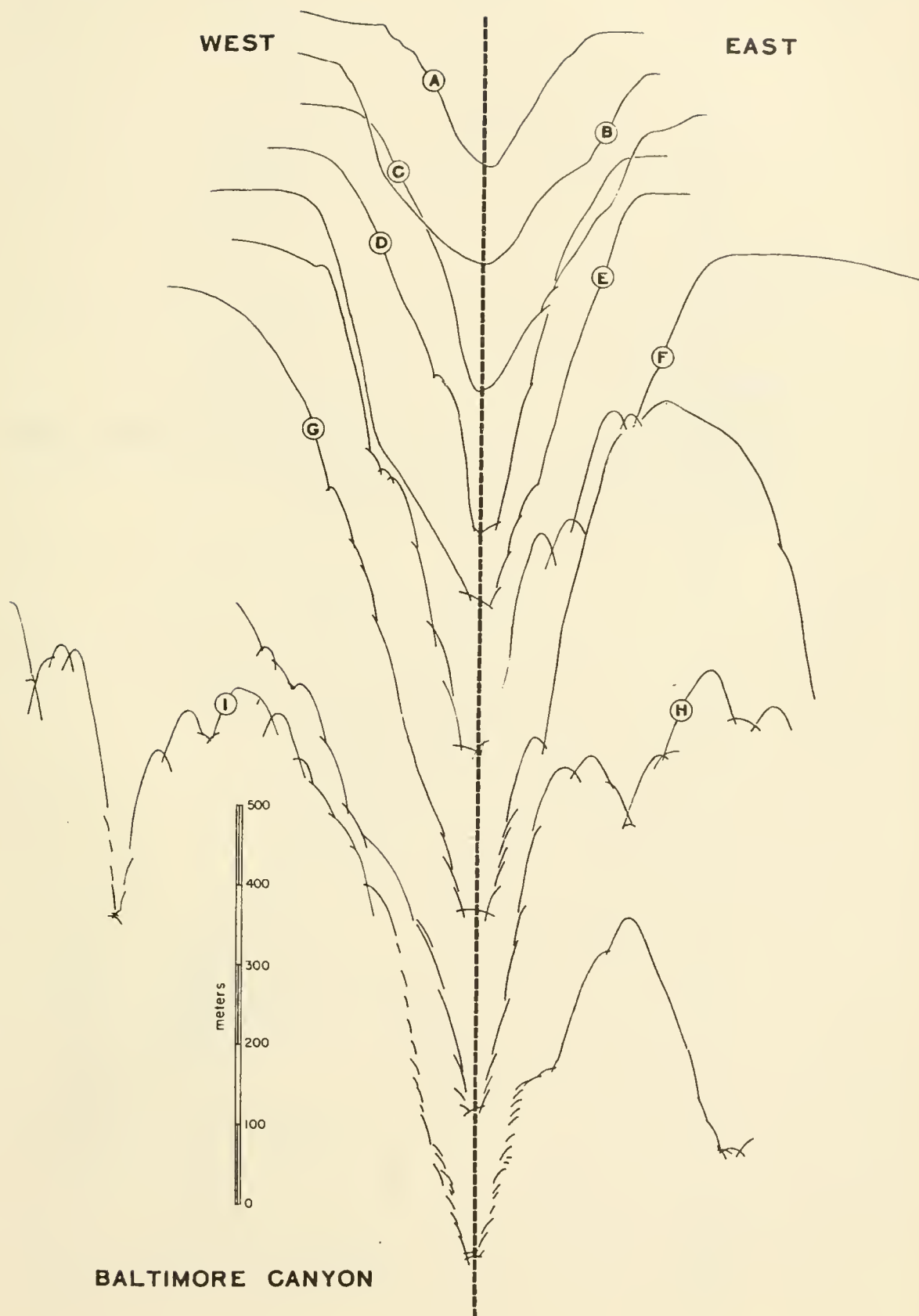


Figure F-3.

Bathymetric map of Oceanographer Canyon showing core,
dredge, and camera run locations.

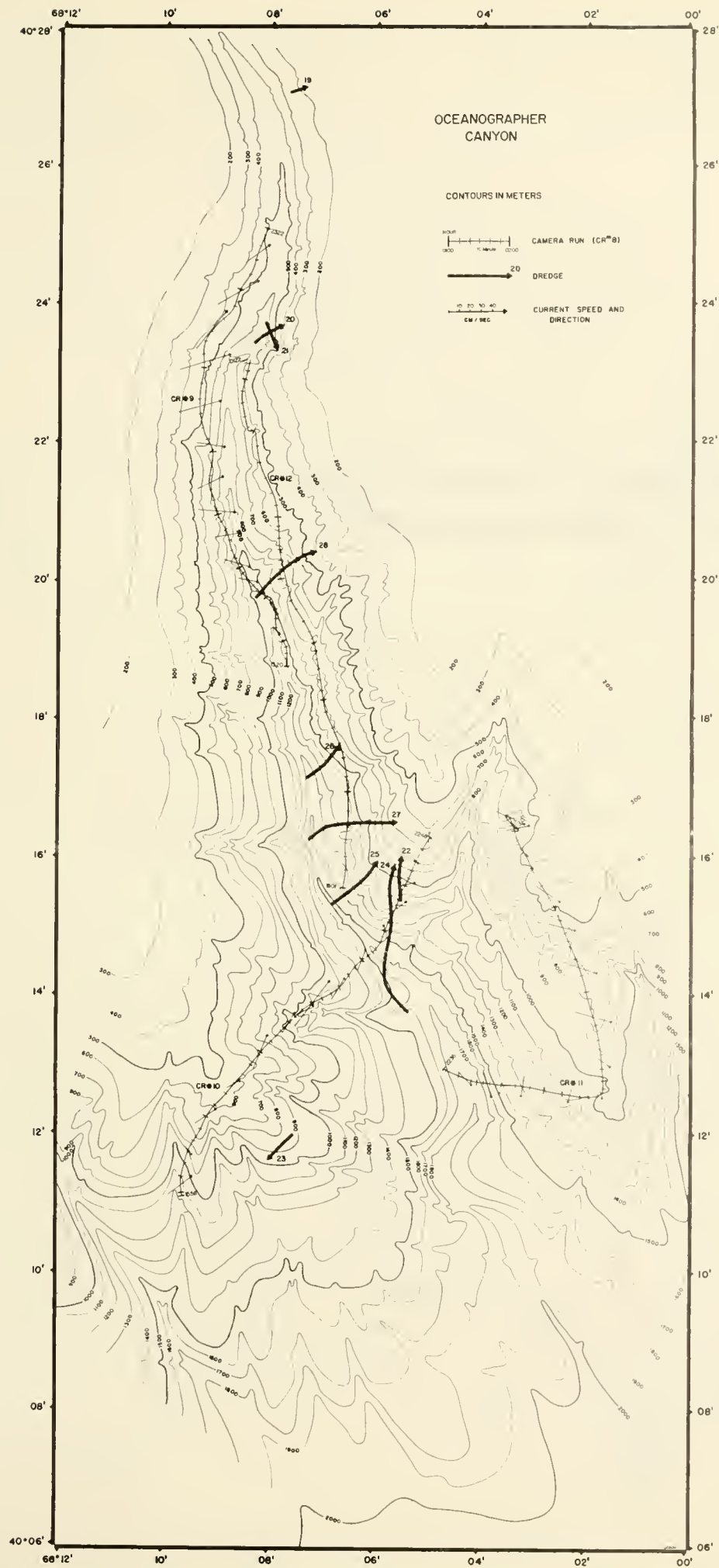


Figure F-4.

Cross-sections at Oceanographer Canyon aligned at the thalweg to show the bottom configuration.

WEST

EAST

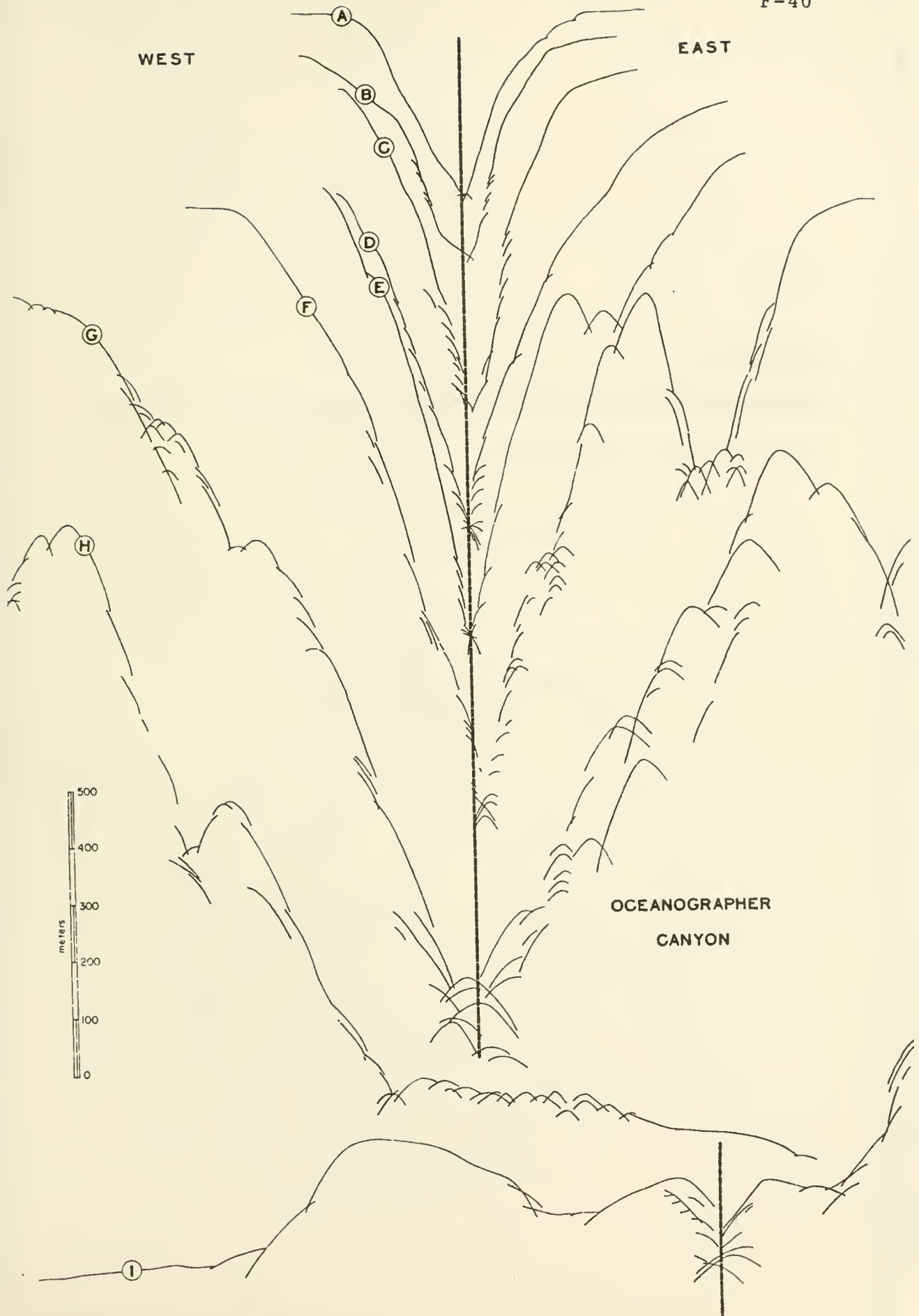
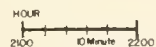


Figure F-5.

Bathymetric map of Lydonia Canyon showing core, dredge,
and camera run locations.

LYDONIA CANYON

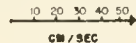
CONTOURS IN METERS



CAMERA RUN (CR#13)

31 DREDGE

29 CORE



CURRENT SPEED AND
DIRECTION

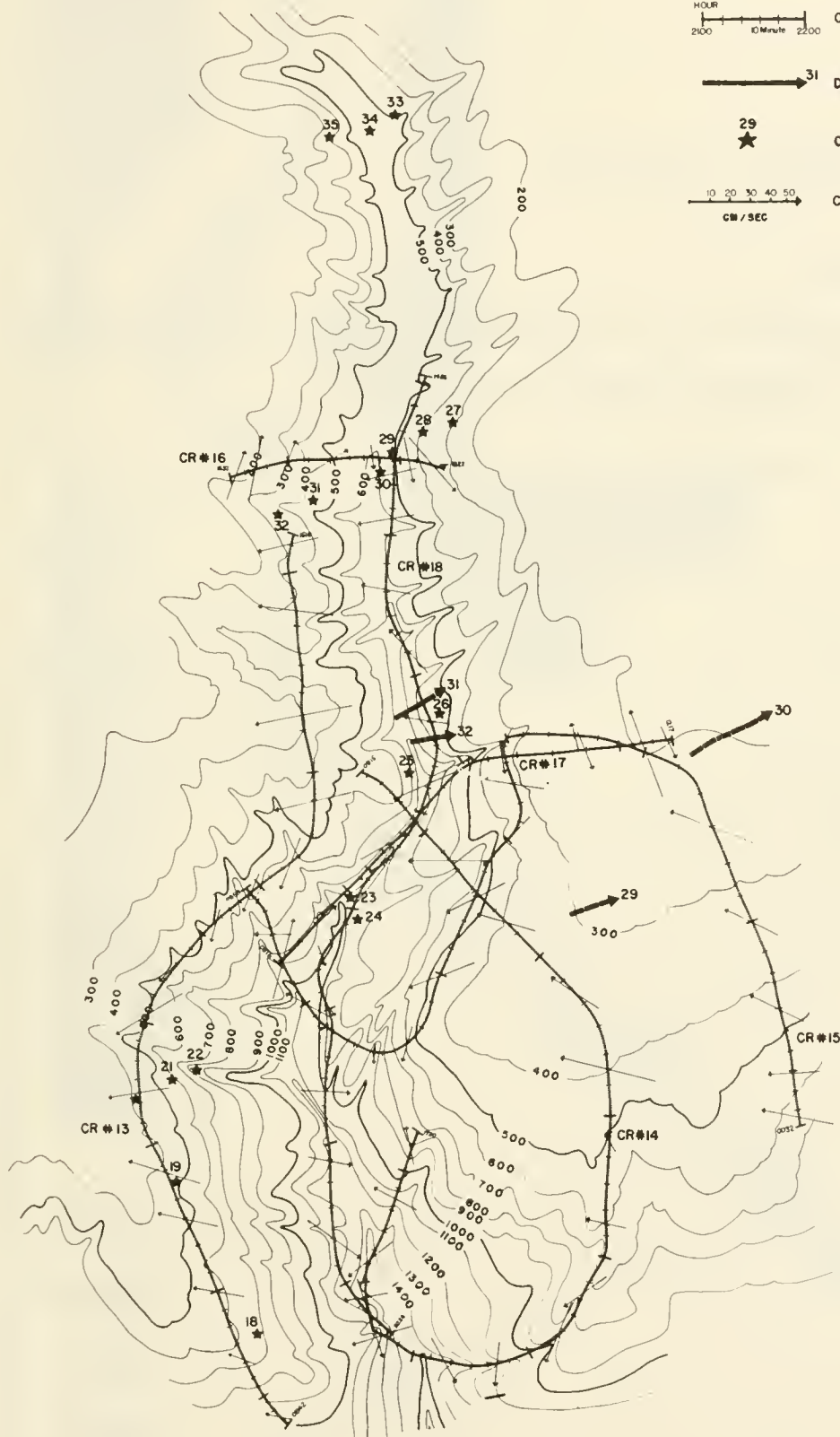


Figure F-6.

Partial geologic map of Baltimore Canyon based on acoustic profiling and photographic evidence.

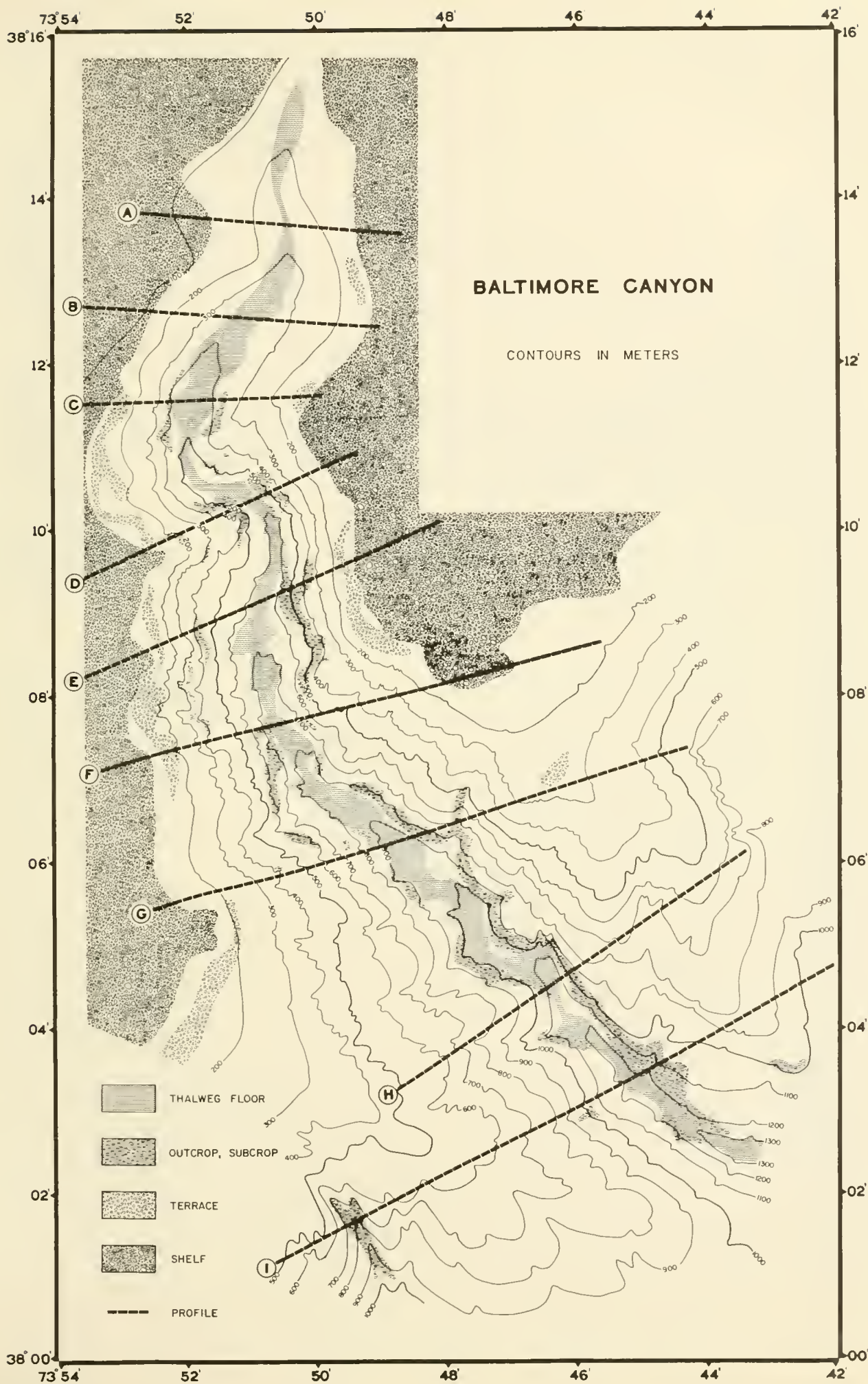


Figure F-7.

Triangular diagram of sediment size distribution for surface samples (gravity core tops) from Baltimore Canyon.

BALTIMORE CANYON
SEDIMENT SIZE DISTRIBUTION
CORE TOP SAMPLES

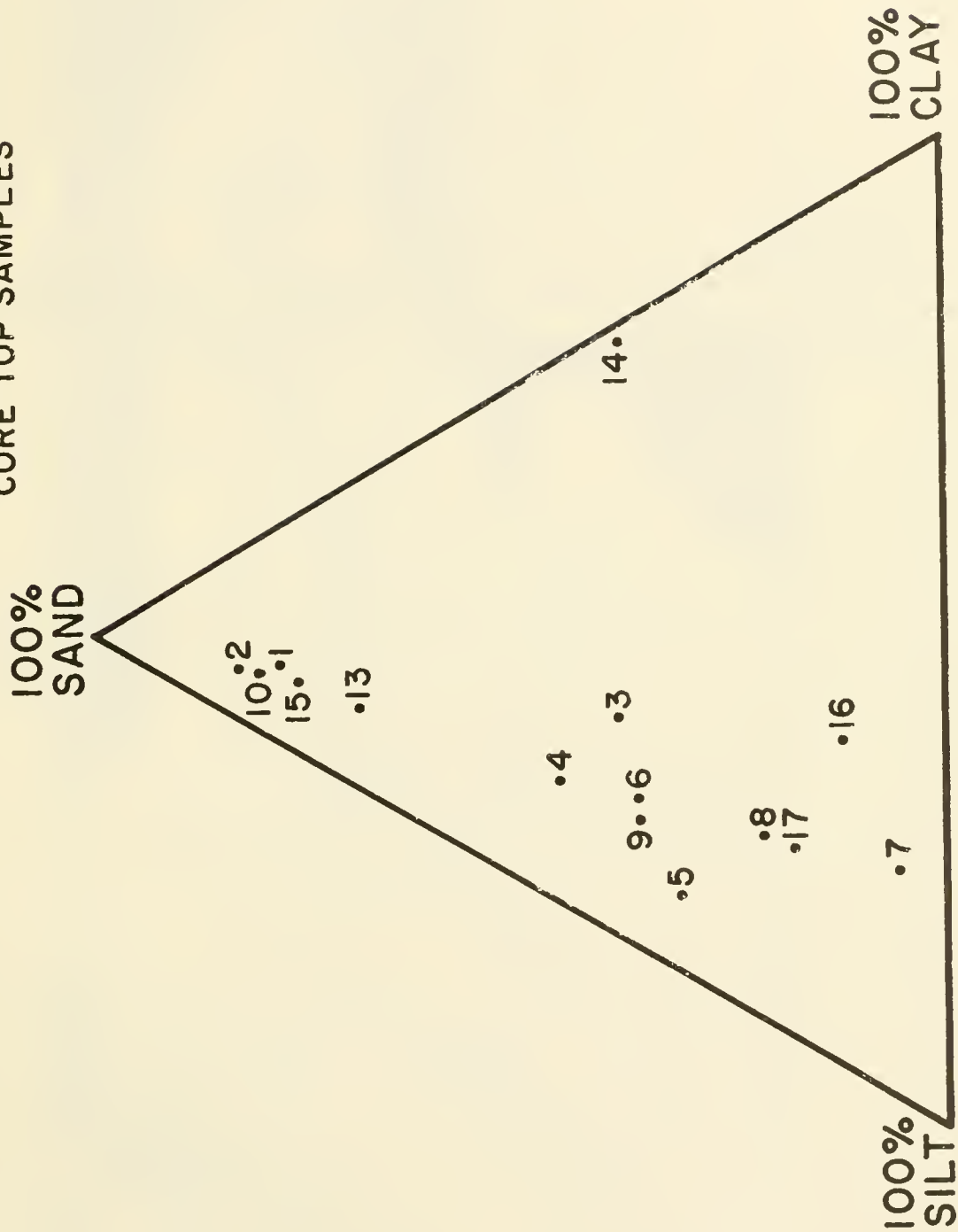


Figure F-8.

Partial geological map of Oceanographer Canyon based on acoustic profiling and photographic evidence.

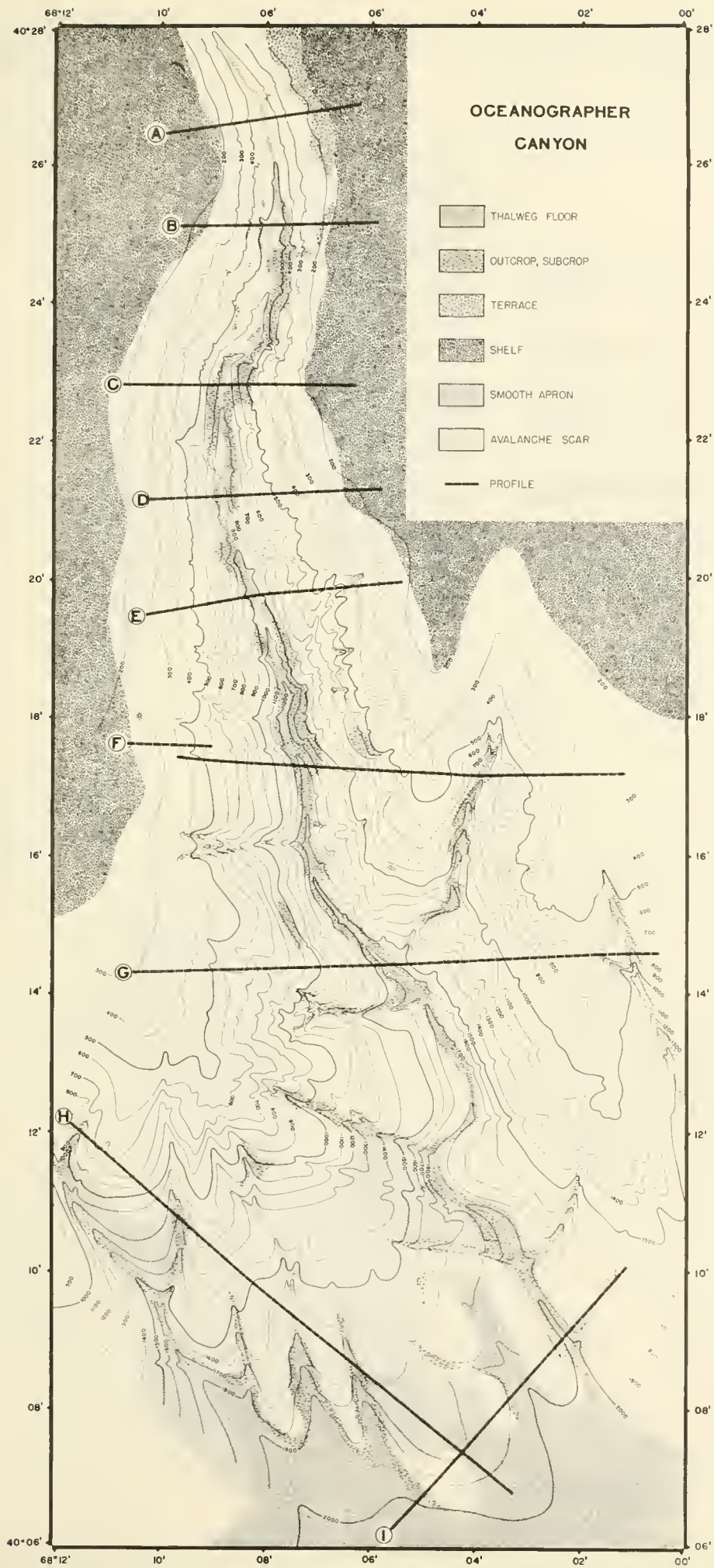







Figure F-9.

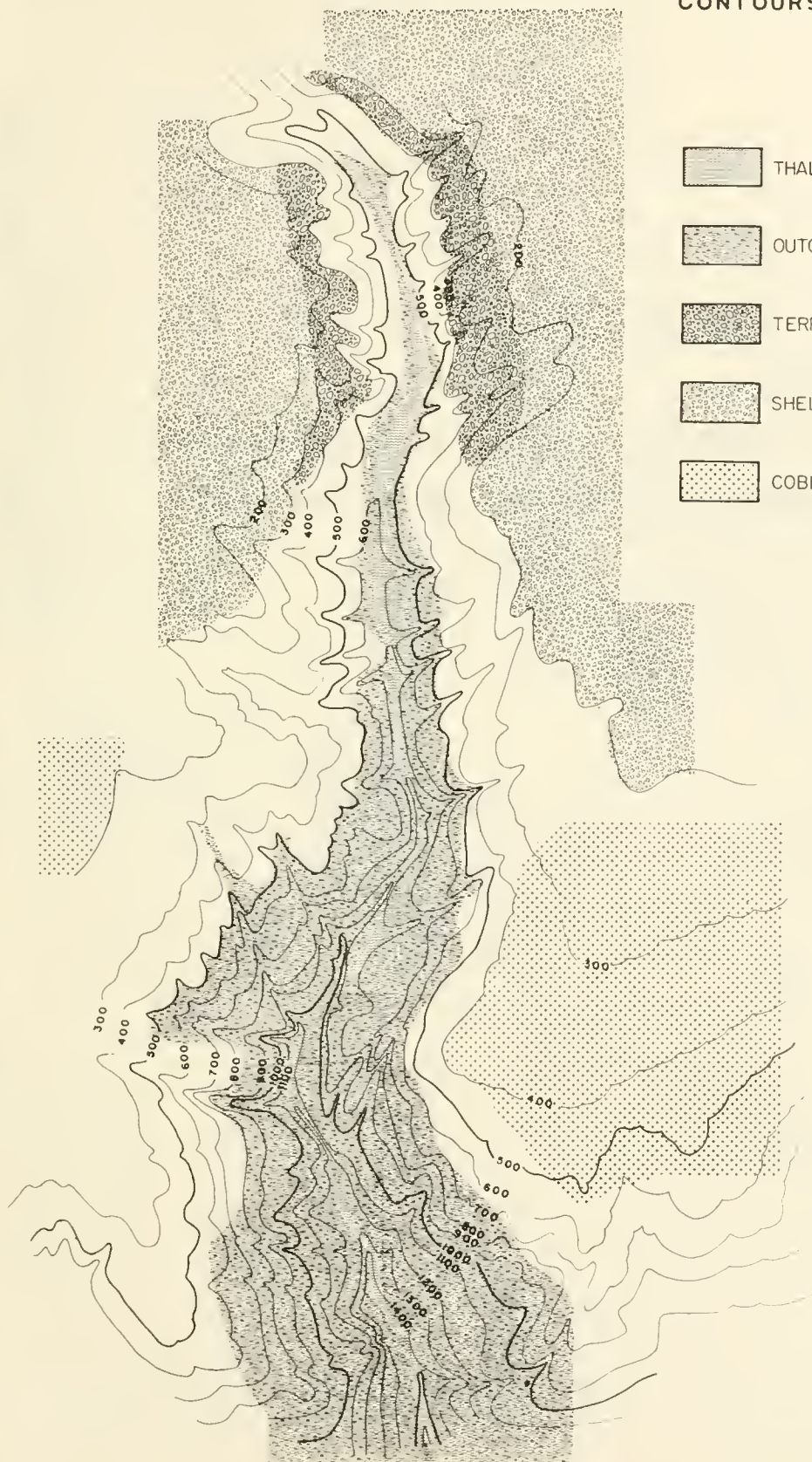
Partial geologic map of Lydonia Canyon based on acoustic profiling and photographic evidence.

LYDONIA CANYON

CONTOURS IN METERS

40°
30'
29'
28'
27'
26'
25'
24'
23'
22'
21'
20'
19'
18'
40°
17'

-  THALWEG FLOOR
-  OUTCROP, SUBCROP
-  TERRACE
-  SHELF
-  COBBLES



67° 45' 44' 43' 42' 41' 40' 39' 38' 37' 36' 35' 34' 33'

Figure F-10.

Triangular diagram of sediment size distribution of surface samples (gravity core tops) from Lydonia Canyon.

LYDONIA CANYON
SEDIMENT SIZE DISTRIBUTION
CORE TOP SAMPLES



Figure F-11.

Wind rose (vector) plot of current directions and normalized velocities in Baltimore Canyon. Arrows indicate general upslope and downslope bearings of the canyon. The lower diagram shows the distribution of current velocities as a histogram of the number of times measured.

BALTIMORE CANYON

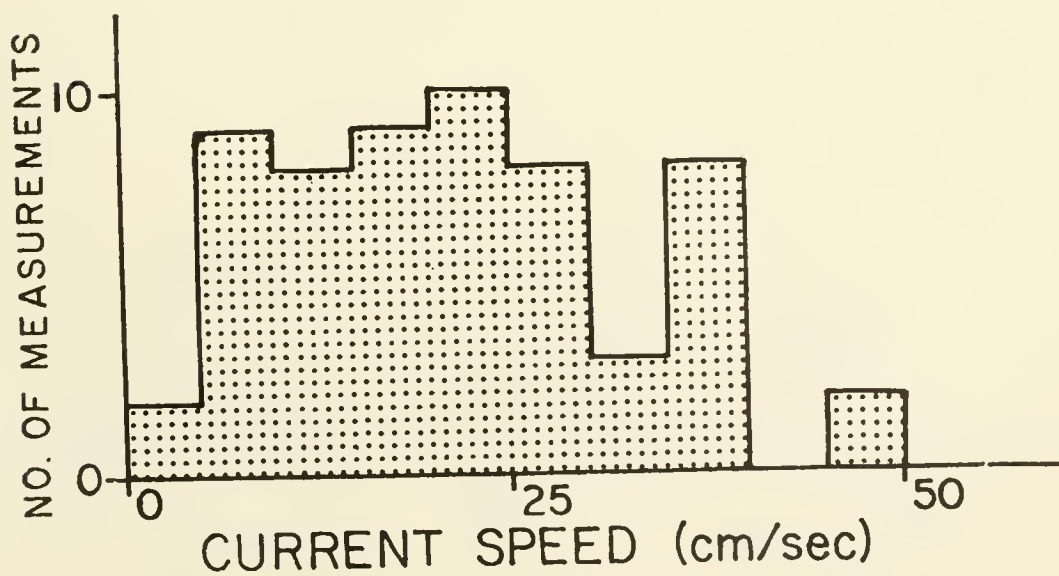
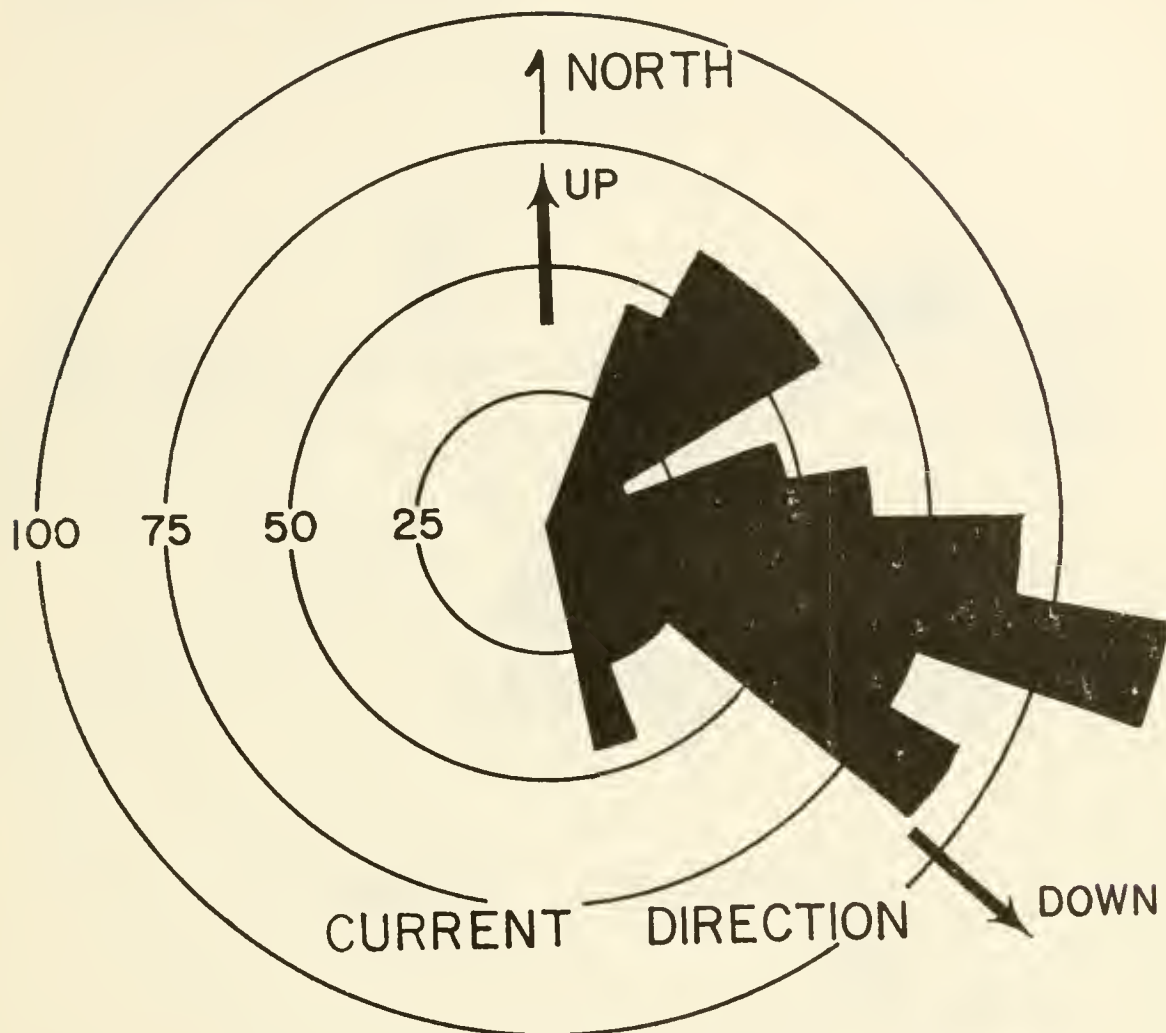


Figure F-12.

Wind rose plot of currents and velocities in Oceanographer Canyon. See also Fig. F-11.

OCEANOGRAPHER CANYON

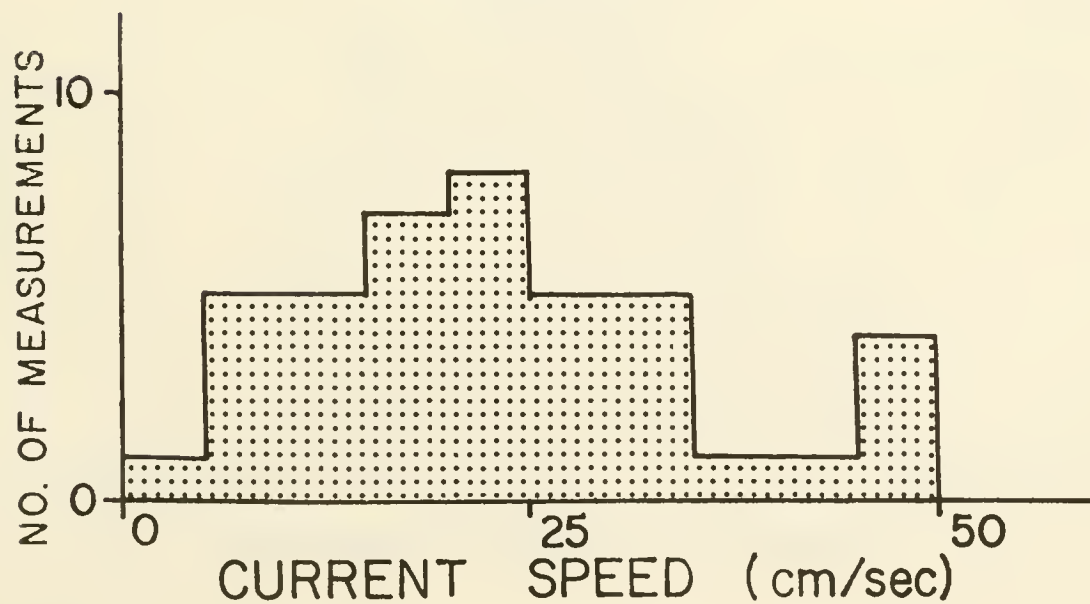
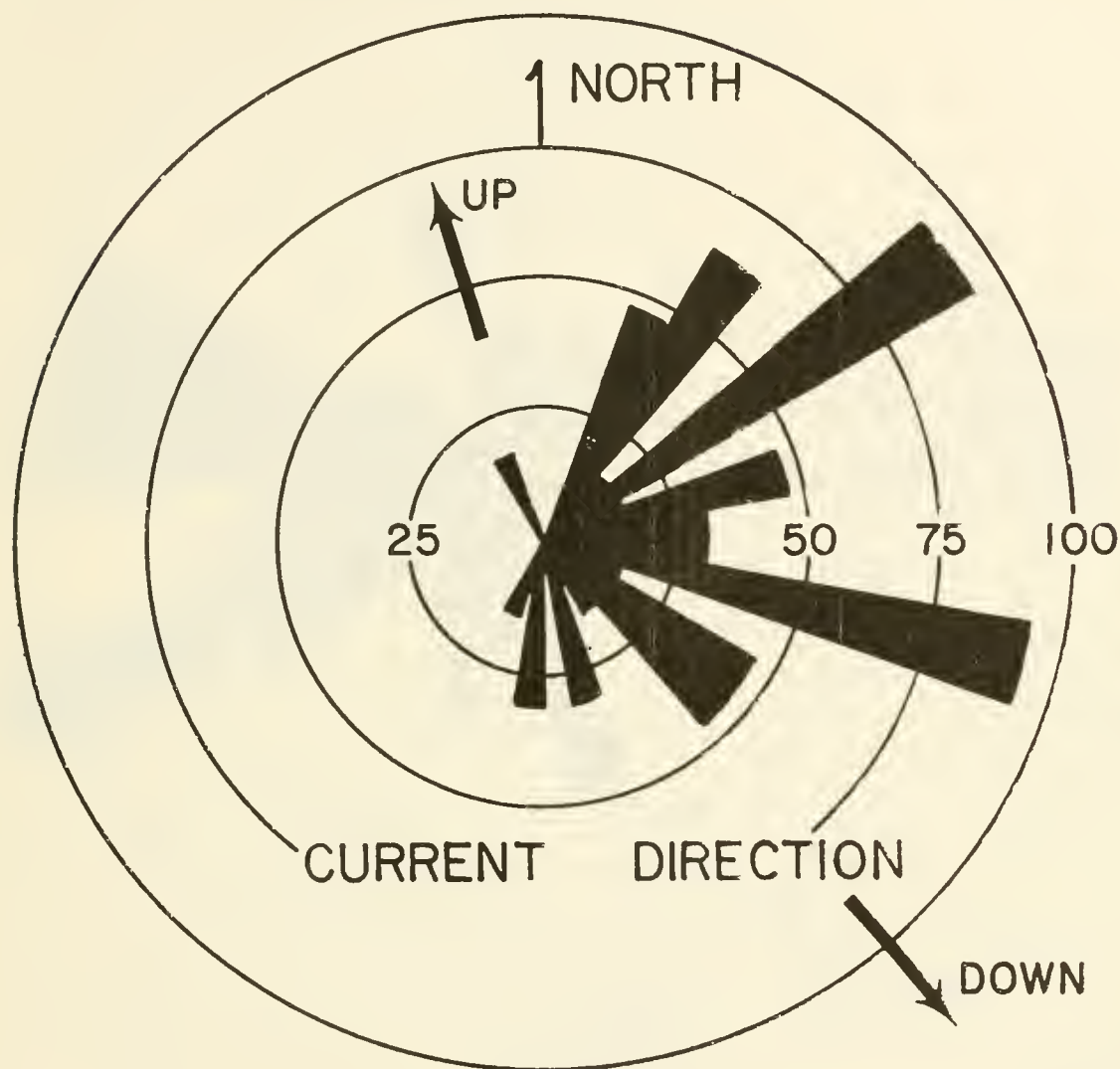


Figure F-13.

Wind rose plot of currents and velocities in Lydonia Canyon. See also Fig. F-11.

LYDONIA CANYON

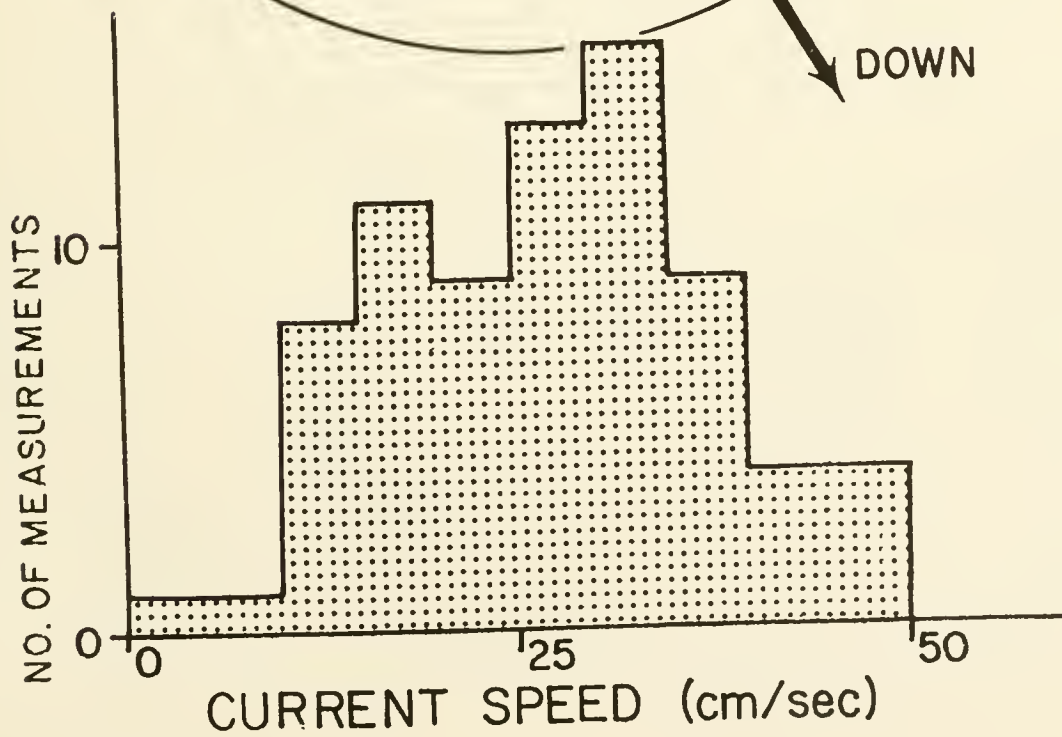
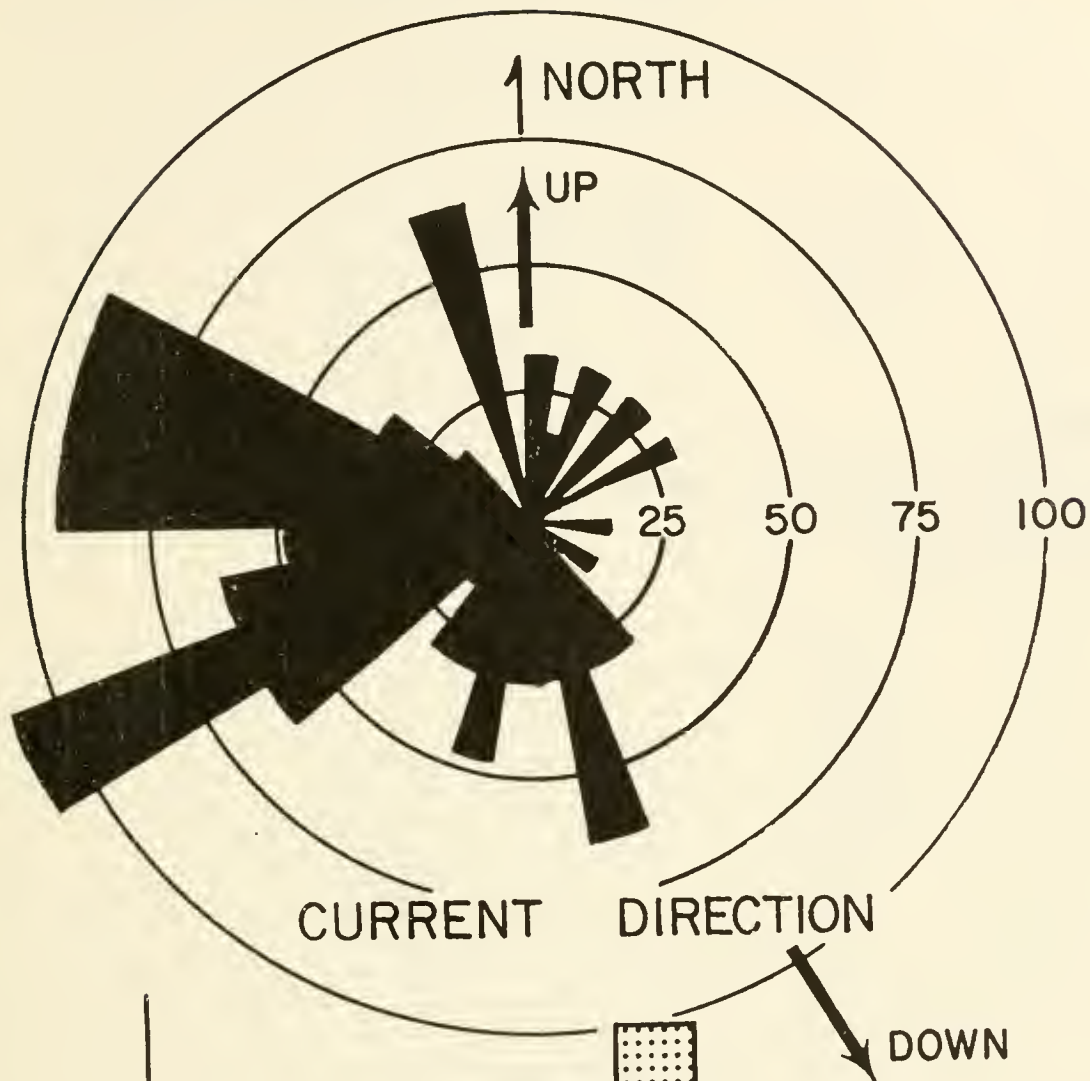


Figure F-14.

Temperature profiles for Baltimore, Oceanographer and
Lydonia Canyons.

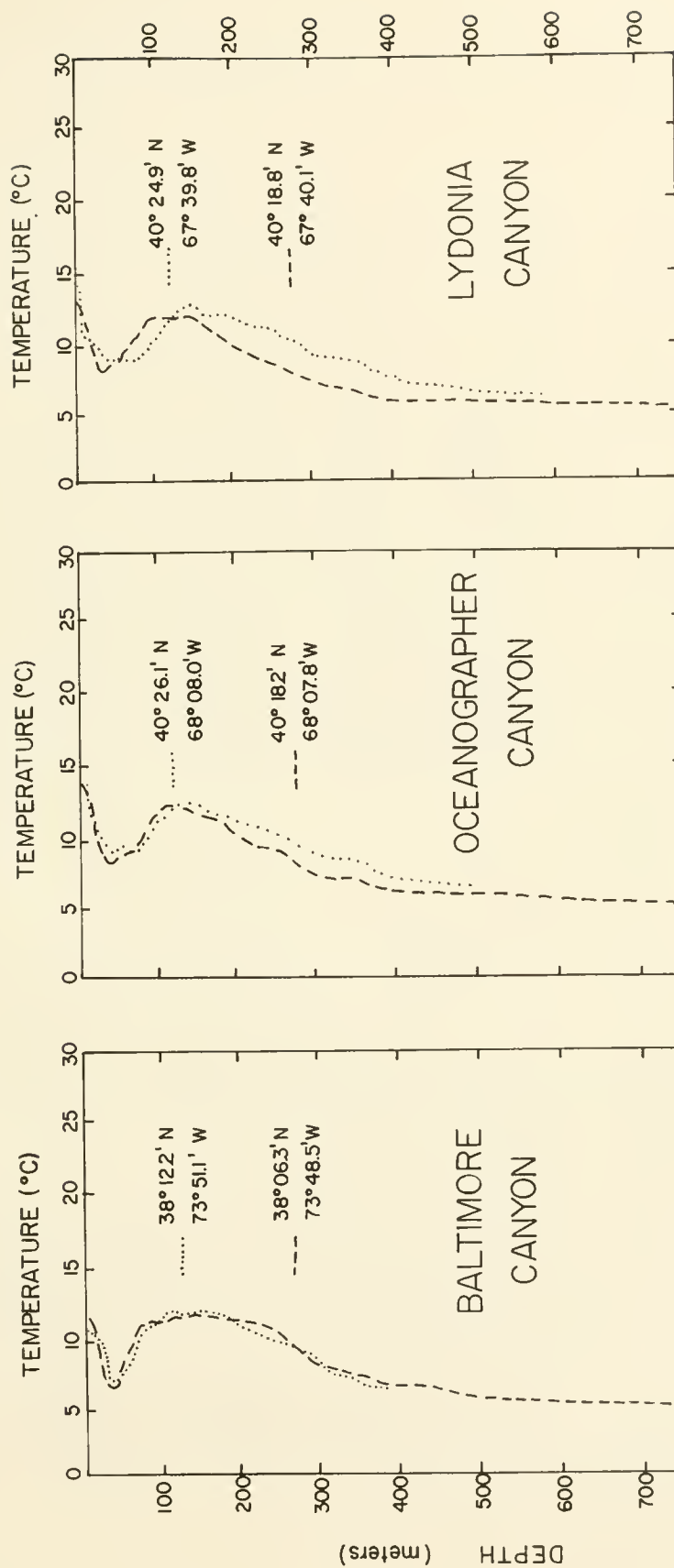


Table F1: Dredges from Baltimore Canyon

<u>Baltimore Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Comments</u>
D-1-A	southwest flank	612-212	-	-	Medium greenish-grey mud, semi-consolidated	diatoms
D-1-A ₁	southwest flank	612-212	-	-	Marly fragments similar to D-1-A	
D-1-B	southwest flank	612-212	-	-	Dark brown fossiliferous limy claystone	pelecypod frags.; diatoms
D-1-C	southwest flank	612-212	-	-	Gravel and cobbles	
D-2-A	west wall	400-350	-	-	Greenish-grey silty clay, consolidated	
D-5-A	northeast wall	160-155	-	-	Dark grey consolidated clay	Quaternary
D-5-B	northeast wall	160-155	-	-	Dark grey fossiliferous mudstone, burrowed	pelecypods
D-7-A	northwest wall	575-320	48.6	25.8	Fine light grey silty conglomerate with black lithic fragments	

Table F1 (cont.)

<u>Baltimore Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Comments</u>
D-7-B	northwest wall	575-320	73.7	6.7	Greenish-black very coarse glauconitic sandstone	
D-7-C	northwest wall	575-320	-	-	Dark greenish-grey coarse sandstone	
D-7-D	northwest wall	575-320	-	-	Very coarse conglomeratic sandstone ;	
D-7-E	northwest wall	575-320	-	-	Black fine grained glauconitic boulder	
D-7-F	northwest wall	575-320	-	-	Rounded brownish-red burrowed boulder	
D-7-G	northwest wall	575-320	-	-	Hard tan conglomerate with rounded lithic & quartz grains	pelecypods
D-7-H	northwest wall	575-320	-	-	Grey fossiliferous medium- grained sandstone	pelecypods
D-7-I	northwest wall	575-320	-	-	Hard grey cobble	
D-7-K	northwest wall	575-320	-	-	Dark greenish-grey coarse sandstone	

Table F1 (cont.)

<u>Baltimore Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Comments</u>
D-7-M	northwest wall	575-320	-	-	Black aphanitic metamorphic rock	
D-9	west wall	925-910	-	3.5	Dark brownish-grey clay, consolidated	
D-13	west wall	875-700	-	-	cobble	
D-15-A	west wall	500-215	11.1	3.2	Dark brownish grey fossil- iferous silty clay; consol.	Quaternary; M bathyal forams
D-15-B ₁	west wall	500-215	-	-	Light olive-grey clay, consolidated	diatoms
D-15-B ₂	west wall	500-215	23.0	3.7	Greenish-grey silty clay	Quaternary; M bathyal forams
D-15-C ₁	west wall	500-215	-	-	Laminated tan mudstone	
D-15-C ₂	west wall	500-215	-	-	Similar to D-15-C ₁ but less lithified	
D-16-A	west wall	550-386	66.6	0.9	Greenish-black coarse grained glauconitic sandstone	Quaternary

Table F1 (cont.)

<u>Baltimore Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Comments</u>
D-16-B	west wall	550-386	-	-	Buff-greyish white pebble	Diatoms
D-16-C	west wall	550-386	-	-	Hard grey siltstone, some quartz and lithic granules	Pelecypod casts
D-16-D	west wall	550-386	-	-	Limonite stained conglomerate, rounded quartz and lithic grains	
D-16-E	west wall	550-386	-	-	Dark fine grained rock	
D-16-F	west wall	550-386	-	-	Light grey coarse grained sandstone, glauconitic	
D-16-H	west wall	550-386	-	-	Pebbles	
D-17-A	thalweg axis	560-526	77.3	1.7	Greenish black coarse grained glauconitic sandstone	Quaternary
D-17-B	thalweg axis	560-526	-	-	Hard light grey micaceous sandstone	
D-17-C	thalweg axis	560-526	-	-	Greenish black coarse grained glauconitic sandstone	

Table F2: Dredges from Oceanographer Canyon

<u>Oceanographer Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Age</u>	<u>Comments</u>
D-19-A	east wall	265-190	-	-	Brownish-grey clayey siltstone	barren	
D-19-B	east wall	265-190	21.8	0.7	Greenish-grey consol. siltstone	barren	bathyal forams
D-19-C	east wall	265-190	18.1	1.9	Brownish-grey mud	Quaternary	upper bathyal forams
D-20-A	east wall thalweg	680-415	6.2	1.8	Dark brownish-grey micaceous glauconitic siltstone, moderate consolidation	Quaternary	upper bathyal forams
D-20-B	east wall thalweg	680-415	2.3	-	Brownish-grey clay	Quaternary	upper bathyal forams
D-20-D	east wall thalweg	680-415	-	-	Greyish-black muddy clay, moderately soft	Campanian, Quat. contam.	
D-20-E	east wall thalweg	680-415	3.6	-	Greyish-brown siltstone	barren	bathyal forams; diatoms; org.
D-20-J ₁	east wall thalweg	680-415	-	-	Greyish-brown burrowed siltstone, barren probably a crust		
D-20-J	east wall thalweg	680-415	-	-	yellowish-tan fossiliferous siltstone, well consol.	barren	

Table F2 (cont.)

<u>Oceanographer Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Age</u>	<u>Comments</u>
D-20-K	east wall thalweg	680-415	4.0	2.4	Dark brownish-grey siltstone, semi-consolidated	U Miocene	diatom frags.
D-20-S	east wall thalweg	680-415	15.2	2.2	Dark grey consolidated clay	Quaternary	shelf forams; diatom frags.
D-21	east wall	562-450	24.2	2.3	Reddish-brown clayey siltstone, moderately well consolidated	barren	shelf forams; diatom frags.
D-21-A	east wall	562-450	-	-	Light grey hard mudstone	barren	diatom frags.
D-21-B	east wall	562-450	5.5	8.5	Greyish-pink glauconitic mica- ceous silt; semi-consolidated	Neogene	
D-22-B	northeast wall	1040-780	-	13.5	Light greenish-grey siltstone; moderately well consolidated	barren	
D-22-C	northeast wall	1040-780	-	-	Greenish-grey siltstone; hard and burrowed	barren	
D-24-A	mouth of canyon base of slope	1570-940	3.2	21.1	Greenish-grey micaceous silt	Quaternary	upper bathyal forams; diatoms
D-24-C	mouth of canyon base of slope	1570-940	2.6	11.8	Moderate greenish-brown mud	Quaternary	upper bathyal forams; diatoms

Table F2 (cont.)

<u>Oceanographer Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Age</u>	<u>Comments</u>
D-24-D	mouth of canyon base of slope	1570-940	2.9	22.3	Brownish-grey mud	Quaternary	upper bathyal forams; diatoms
D-24-E	mouth of canyon base of slope	1570-940	-	-	Greenish-grey mud; same as D-24-A	Quaternary	diatoms
D-24-H	mouth of canyon base of slope	1570-940	18.3	12.1	Light grey micaceous silt- stone, well consolidated	Santonian	
D-24-J	mouth of canyon base of slope	1570-940	2.0	-	Greyish-black clayey mica- ceous siltstone, moderately well consolidated	U Turonian/ Coniacian	organic matter
D-25-A	thalweg, west to east	1510-978	22.3	3.7	Greenish-grey mud	Quaternary Cret. contam.	shelf forams
D-25-B	thalweg, west to east	1510-978	26.8	9.5	Moderate greenish-grey silty mud	Quaternary	shelf forams; diatoms
D-25-C	thalweg, west to east	1510-978	8.7	3.5	Brownish-grey mud	Quaternary Cret. contam.	shelf forams;
D-25-D	thalweg, west to east	1510-978	6.0	27.7	Dark grey micaceous silt- stone, mod. well consol.	U Turonian/ Coniacian	diatoms; silicoflagellates

Table F2 (cont.)

<u>Oceanographer Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Age</u>	<u>Comments</u>
D-26-A ₁	thalweg, west to east	1220-935	-	-	Dark grey micaceous silt- stone, well consolidated	U Turonian/ Coniacian	
D-26-A ₂	thalweg, west to east	1220-935	-	-	Moderate dark grey mica- ceous siltstone, well consol.	Santonian	organic matter
D-26-A ₃	thalweg, west to east	1220-935	-	-	Soft greenish-grey mud	Quaternary	diatoms
D-26-B	thalweg west to east	1220-935	33.7	7.4	Dark tan hard micaceous siltstone, well consol.	barren	shelf forams
D-26-C ₁	thalweg, west to east	1220-935	10.2	-	Grey mud	barren	diatoms
D-26-C ₂	thalweg, west to east	1220-935	-	-	Hard tan micaceous siltstone	Quaternary	upper bathyal forams
D-26-D	thalweg, west to east	1220-935	-	-	Rusty-brownish micaceous silt- stone, well consolidated, probably weathered D-26-A ₁	Cretaceous	
D-27-A	thalweg, west to east	1435-660	-	-	Grey consolidated clay	Quaternary	diatoms; organic matter

Table F2 (cont.)

<u>Oceanographer Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Age</u>	<u>Comments</u>
D-27-B	thalweg, west to east	1435-660	13.8	5.7	Dark grey micaceous silt- stone	Santonian	organic matter
D-27-C	thalweg, west to east	1435-660	19.1	9.1	Greenish-grey mud	Quaternary	shelf forams; diatoms
D-28-A ₁	west wall	985-350	23.9	-	Dark grey micaceous silt- stone, mod. well consol.	U Turonian/ Coniacian	upper bathyal forams
D-28-A ₂	west wall	985-350	-	-	Medium grey micaceous silty sandstone, well consol.	Turonian/ coniacian	upper bathyal forams
D-28-B	west wall	985-350	29.6	3.7	Greensih-grey mud	Quaternary	upper bathyal forams; diatoms
D-28-C	west wall	985-350	29.1	14.7	Greyish-black micaceous silt- stone, mod. well consol.	Turonian/ Coniacian	rare organics
D-28-D	west wall	985-350	24.4	20.2	Dark grey micaceous silt- stone, mod. well consol.	Turonian/ Coniacian	upper bathyal forams; diatoms
D-28-E	west wall	985-350	-	-	Moderate dark grey semi- consolidated clay	Quaternary	diatoms
D-28-F	west wall	985-350	16.1	3.1	Greenish-grey mud	Quaternary	upper bathyal forams; diatoms

Table F2 (cont.)

<u>Oceanographer Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Age</u>	<u>Comments</u>
D-28-G	west wall	985-350	-	-	Dark greenish-grey siltstone mod. well consolidated	Quaternary	some organics
D-28-H	west wall	985-350	5.5	11.5	Dark greenish-grey fossiliferous (pelecypods & gastropods) siltstone, mod. well consol.	Quaternary	diatom frags.
D-28-I	west wall	985-350	-	-	Hard pebble - light grey limestone	barren	
<u>Camera Stations</u>							
12-A			12.9	4.4	Very soft dark grey to green mottled fine-grained mud	E Campanian	contam. org.
12-B			6.8	2.4	Greyish-black micaceous clay	Coniacian (?)	organic matter
12-C			6.5	3.6	Greyish-black micaceous clay- rich siltstone, mod. well consolidated	Turonian/ Coniacian	organic matter

Table F3: Dredges from Lydonia Canyon

<u>Lydonia Sample</u>	<u>Location</u>	<u>Depth</u>	<u>%Sand</u>	<u>%Carbonate</u>	<u>Lithology</u>	<u>Age</u>	<u>Comments</u>
D-29-A	east wall	305-302	-	-	Greyish-brown mud	mixed Cret, Eocene, and Miocene	contaminated
D-31-A	east wall	680-379	75.8	1.8	Greyish-brown glauconitic sandy siltstone, mod. well consolidated	U Miocene	diatoms; organic matter
D-31-B	east wall	680-379	10.3	16.9	Light tan semi-consolidated marl	U Miocene	diatoms
D-32-B	east wall	613-430	4.2	2.1	Dark grey glauconitic micaceous siltstone, semi-consol.	Turonian/Coniacian	bathyal forams; organic matter
D-32-C	east wall	613-430	6.3	1.2	Greyish-brown moderately well consolidated glauconitic siltstone	barren	diatom frags.
D-32-D	east wall	613-430	4.7	5.0	Crumbly dark greyish-brown siltstone, soft	Quaternary	shelf forams; diatoms
D-32-E	east wall	613-430	6.1	1.2	Brownish-grey glauconitic silt	Quaternary	diatom frags.
Camera Sta. 13					Greyish-brown mud	Quaternary	
Camera Sta. 14					Yellow/greyish-white marl	M Eocene	diatoms

Table F4: Cores from Baltimore Canyon

Core	Location	Water Depth (m)	Core Length (cm)	Sample Depth (cm)	%Sand	%Silt	%Clay	%Carbonate
1	thalweg	370	10	top 6	74.3	16.3	9.4	7.4
2	thalweg	453	10	top 6	52.6 82.8 61.8	42.7 12.6 28.1	4.7 4.7 10.2	- 4.0 -
3	thalweg	580	4	base	38.2	40.2	21.6	6.1
4	thalweg - east wall	635	67	top 44	45.9 57.8	43.4 37.4	10.7 4.8	7.1 -
5	thalweg - east wall	780	64	top 21	31.8 53.6	60.7 35.8	7.5 10.6	12.1 -
6	thalweg - east wall	830	61	top 40	35.9 26.8	49.5 42.9	14.6 30.7	9.6 -
7	thalweg - west wall	1037	74	top 49	5.1 1.5	72.4 91.2	22.5 7.3	10.0 -
8	east wall	709	42	top 28	19.2 25.3	60.9 48.8	19.9 25.9	9.8 -
9	east wall	490	60	top 40	35.6 21.2	50.8 72.1	13.6 6.7	13.7 -
10	east wall	340	32	top 21	79.5 75.5	14.3 19.3	6.2 5.2	10.5 -
11	east wall	core lost	-	-	-	-	-	-
12	east wall	core lost	-	-	-	-	-	-
13	east wall	310	64	top 42	69.4 81.5	23.4 4.8	7.2 13.7	12.2 -
14	east wall	420	32	top 22	37.8 11.3	2.0 59.0	60.2 29.7	6.5 -
15	thalweg	555	73	top 48	75.7 65.3	17.0 23.2	8.0 11.5	3.7 -
16	west wall	500	76	top 50	11.4 52.2	55.7 38.9	32.6 8.9	10.9 -
17	west wall	353	61	top 40	17.2 12.3	62.9 73.9	19.9 13.9	13.6 -

Table F5: Cores from Lydonia Canyon

Core	Location	Water depth (m)	Core Length (cm)	Sample Depth (cm)	%Sand	%Silt	%Clay	%Carbonate
18	west wall	705	4	base	46.4	34.4	17.4	-
19	west wall	495	6	top	78.3	10.3	11.4	3.5
20	west wall	430	36	top	81.5	12.6	5.9	-
21	west wall	715	28	top	71.4	19.7	8.9	3.5
22	west wall	850	72	top	8.0	55.0	36.9	-
23	thalweg -	940	57	top	53.2	34.0	12.8	4.8
24	thalweg -	875	45	top	46.9	42.2	10.9	-
25	thalweg -	840	4	base	24.7	63.4	11.9	7.6
26	thalweg	500	62	top	28.6	57.3	14.3	-
27	east wall	318	core lost	top	57.0	36.8	6.3	4.6
28	east wall	389	core lost	top	60.7	31.9	7.4	-
29	west wall	528	70	top	59.6	32.5	7.9	4.1
30	thalweg	625	10	top	67.7	25.9	6.4	-
31	west wall	450	59	top	57.6	28.9	13.5	-
32	west wall	346	3	base	75.9	18.3	5.9	2.8
33	thalweg	440	10	top	45.2	43.0	11.8	-
34	thalweg -	560	59	top	-	-	-	-
35	west wall	350	3	base	74.8	19.3	5.9	3.3
				top	65.8	17.5	16.7	-
				top	80.5	13.4	6.1	5.2
				top	87.4	8.9	3.7	-
				top	54.1	35.8	10.2	-
				top	52.9	38.6	8.5	-
				base	20.5	50.2	29.2	5.5
				top	49.7	37.1	13.2	4.5
				top	48.8	38.8	12.4	-
				top	70.6	22.4	7.0	0.8
				top	44.1	43.8	12.1	-
				base	39.1	44.7	10.5	-

